# TRAMWAY TRACK CONSTRUCTION AND MAINTENANCE

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R. BICKERSTAFFE HOLT

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# TRAMWAY TRACK CONSTRUCTION AND MAINTENANCE

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BY

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# PREFACE

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R. BICKERSTAFFE HOLT.

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# FOREWORD

"WHAT'S WRONG WITH THE TRACK?"

So much has been written about tramway permanent way during the past ten years that one might feel tempted to apologise for again introducing this subject, were it not for the fact that, speaking generally, all is not well with the permanent way. The managers of overburdened systems will aver that there is nothing permanent about their way but its appetite for assimilating what would otherwise be handsome trading profits. One must sympathise with those gentlemen who are struggling hard to meet the expenditure on the maintenance of tracks which they did not design, and in the maintenance of which, in many cases, they have no say. It is truly a case of bearing the other man's burden.

Engineers and managers throughout the country will tell you that they have spared no expense to secure a really permanent way; every modern improvement has been tried, and yet one regrets to relate that the report from many of the sources—too many—is that the cost of maintenance is still high, and shows an alarming tendency to increase each successive year. It cannot be wondered at, therefore, that these people are all unanimous in their condemnation of the "rigid" form of construction, attributing to it all the evils the track is heir to. It is frequently stated that the rigid form of construction has been proved to be unsatisfactory. It has also been alleged that the rigid form of construction has a deleterious effect upon the rolling stock,

one writer having gone so far as to assert that "the rigidity of the track has shortened the life of the rolling stock to such an extent that tramway cars, for this reason, have only one quarter the life of railway coaches." Such a sweeping statement would obviously not bear critical analysis, even if the railway coach and the tramway car were at all comparable. There is obviously a vast difference between the work performed by the fast, but regular travelling, drawn bogie coach, running on easy grades and curves, and the work done by the driven tramway car, particularly of the single-truck type, travelling as it does over routes through tortuous streets, with cambered tracks, steep grades, and sharp curves; to which must be added the enormous strain caused by constant use of powerful brakes on grades, at stopping places, and in avoiding collision with the ordinary vehicular traffic. It may be readily admitted that imperfections of the track are the cause of a considerable amount of damage to, and expenditure on, the rolling stock; but this is by no means due to the rigidity of the track; but to the failure of those responsible for its construction and maintenance to obtain a rigid track. It is the looseness and irregularities in the track that damage the rolling stock and in turn react through the car upon the track itself.

It must be granted that where the subsoil renders it possible to lay a flexible track, such a method of construction would be in many ways superior to the rigid form of construction; but it must be borne in mind that the subsoil and local conditions and the requirements of the vehicular traffic in this country in regard to the surface of the paving, in addition to third party risks, are such, in the majority of places, as to prohibit the use of a flexible track. The rigid method of construction in one form or another is the standard form

for this country; but it is by no means a failure, and tracks have been and are being constructed on rigid lines on which the expenditure on maintenance has been reduced to a minimum.

To parody a recent literary catch phrase, "What's wrong with the track?" There are usually three things wrong with a defective track. (1) Either the design was unsuitable for the locality, or (2) the materials were defective in quality or application, or (thirdly and generally) the supervision of the construction and maintenance has been inadequate and defective. The supervision of track construction is an almost unknown art, and the lack of it is responsible for most of the present day track troubles.

A track may have been well and suitably designed, the materials and workmanship may have been the best procurable, and still the track may fail to sustain the burden of the frequent service of heavily-laden, high-speed tramway cars without correspondingly heavy maintenance charges.

It is not intended to reflect upon the skill and professional integrity of the engineers responsible for the work; but the fact remains that much of the tramway permanent way in this country has been constructed by engineers and contractors who, although skilled in the construction of roads and paved streets, had nevertheless little or no experience in the requirements of a modern electric tramway track, whilst their knowledge of track maintenance was *nil*. Knowledge of track construction was never acquired in the drawing office, nor in the actual construction of new track work alone. The actual requirements for first-class work are only to be found during a daily and almost hourly attention to the maintenance of an existing track. It is only by the constant observation of the phenomena of track movements that the cause of track troubles

can be traced. It has been declared that "any competent street contractor can lay a tramway track; that the work presents no difficulties; that it consists merely in laying two steel rails above a bed of concrete, packing the same, and finally paving up in the usual manner." This is, of course, quite true, but these are the tracks that very soon "speak back to you," to borrow the expressive phrase of one of our prominent tramway managers. The same applies to the supervision—no expense has been spared in providing assistant engineers, foremen, and gangers—the surveys and levels may have been accurately prepared, and the curves well set out, and each of the gangs well watched; but the whole has been spoiled by the lack of knowledge of maintenance and of the subsequent behaviour of the track in operation. Here, then, is the chief cause of high expenditure on maintenance, and the pity of it all is that these men may continue to lay track after track without ever gaining any knowledge of the working conditions of the track beyond what they see during the ridiculously short period of maintenance. They undoubtedly become adepts at quick construction, but they are unaware of incipient flaws in their work, which are certain to develop to an amazing extent long after they have completed the work.

There is no question of the work having been scamped; but there are a hundred and one small items which require constant attention if the rigid form of construction is to be made a success from a maintenance point of view. The cause of the present day track troubles lies not in the rigid method of construction, but in the failure of those responsible for the construction of the track to lay a rigid track.

It is not intended in these pages to review the various methods of track construction which have been

adopted in this country since the advent of electric traction. Such a review would no doubt be interesting from an historical point of view, but it would not serve the present purpose, which is to deal with the construction and maintenance of tramway track in a practical manner in the hope that it may be of some little service to tracksmen and tramway men generally.

# Tramway Track Construction and Maintenance

## CHAPTER I.

### CONCRETE FOUNDATIONS.

MANY engineers cherish the belief that their tracks have at least one permanent feature in the concrete foundation. It is regrettable, but inevitable, that the majority of those holding this belief will be disillusioned when they have to reconstruct. The platitude, "concrete foundations may be said to be good for all time," will no longer be of service to writers on tramway permanent way. Much of the trouble experienced in regard to loose rails and paving is attributable to defective concrete foundations. On many tramway tracks which have been reconstructed during the past few years, it has been found that a considerable amount of the concrete is fractured beneath or near to the rails and longitudinally with them. Figs. 1 and 2 illustrate particularly bad examples of fractured concrete. In both these instances the concrete has failed to support the load, and in Fig. 1 the fractured portion has subsided with the filling of a sewer trench. The same result has occurred in Fig. 2, except that the concrete has followed the subsidence due to a "wash out" caused by spring water working beneath the track. Fig. 2 shows clearly that the rails on this track were above the shattered and sunken foundation, in fact they

were supported upon mounds of packing in layers, indicating that the track had been raised several times, and that each time there had been sufficient space between the rail flanges and the old packing when the rails were lifted to insert the new packing. It is obvious that there is but one thing to do with such cases of fractured concrete foundations as those shown in Figs. 1 and 2, and that is to take them up and replace them.

Of course these are bad examples, but no fractures, however small and indistinct, can be neglected during the reconstruction of the track; they must be traced, cut out, and the concrete renewed in wide trenches. As previously stated, such fractures generally occur beneath or near to the rails, and are not discernible until the rails have been removed; but they will frequently be found to occur where the track has previously required much attention in the way of "patching."

In addition to the larger fractures, the more pronounced of the finer cracks referred to may be clearly seen in Fig. 1. There are several reasons for these fractures. In the first place, on almost every tramway system, everything was sacrificed for speed in construction, so as not to inconvenience the general public. This led to (1) hurried mixing of the concrete, (2) careless watering, and (3) either the cars or vehicular traffic were permitted to run over the new work before the concrete had had reasonable time to mature.

Upon examination, many of the old concrete foundations show signs of being short of cement in some places and possessing too much in others. This fact is eloquent of the method adopted in mixing the mass; one can almost picture the banker, and the material being turned over "twice dry and twice wet," a man with a bucket sluicing a plentiful supply of water over

Fig. 1.—Showing Fractured and Sunk Concrete Foundations.

the whole, and the wet cement flowing off the stage on all sides. This is what undoubtedly occurred, and the result is evident in the concrete referred to. Most of the cement was precipitated, and some of the

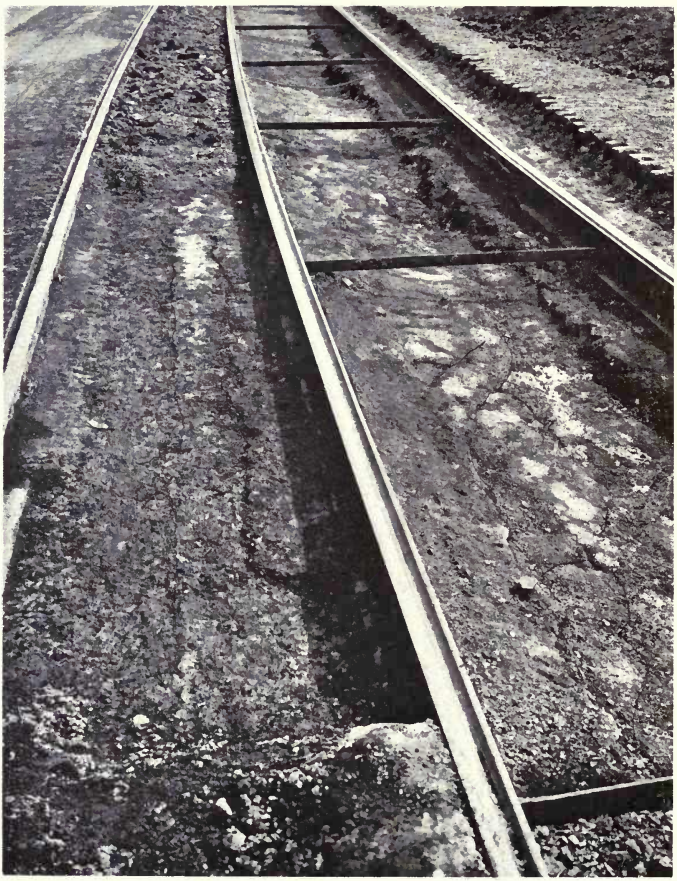


Fig. 2.—Showing Settlement of Fractured Concrete Foundations.

aggregate at the bottom got more than its share of the matrix, and the remainder simply got a covering of cementy water.

In order to avoid a recurrence of such costly defects the following method of mixing the concrete has been adopted on the Leeds and other tramways, which has

the advantage of being simple, and effectually preventing overwatering: The cement and sand are first of all mixed dry on a stage having sides about 4 in. high, and are then spread round the stage in the form of a basin, water is added, and the mixture is turned over until a plastic mass of the nature of floating or mortar is prepared, and spread over the stage. No further water is used, and the broken stone, having been previously wetted, is spread over the composition in a layer, and then the whole mass is turned over twice, and thoroughly incorporated before being laid in the bed. It takes very little more time to mix the concrete in this manner, and the results will certainly justify the extra cost of the work. Without doubt many fractures have been caused by the unloading and handling of rails upon concrete which is merely hard enough to walk on, and this consideration alone ought to settle finally the question as to whether the concrete should be laid before the rails or afterwards. When the concrete is laid before the rails it is practically impossible to maintain a uniform space between the rails and the concrete foundation for the packing. In such cases the interspace varies between $2\frac{1}{2}$ in. and actual contact with the rail flange, and it is obvious that where the concrete is close up to the rail flange it cannot be packed solidly. In such cases cement grout has been run beneath the flanges, but such a procedure cannot be condemned too strongly. One can never be certain that the grout has entirely filled up the voids. This can be clearly seen when the tracks are being reconstructed, and, again, at the best it is but a thin layer of material between the hammer and the anvil, as it were, which is liable to crack and become pulverised. There is a most important reason for maintaining a uniform space between the rail and the concrete, which has a direct bearing upon the

subsequent renewals, for which provision should be made, as hereafter described.

Another method of laying the concrete consists of laying the rails to their true levels first, and then ramming the concrete round the base of the rail. This method is not recommended, for unless the greatest care is taken in the mixing and laying of the concrete it is liable to "sag" or settle away from the rail base, with the usual result—springing rails and loose paving. Then, again, whilst the concrete is setting, the rails, being exposed, are liable to leave the surface of the concrete, and there is no other means of rebedding the rails except by means of cement grout, which, as before mentioned, is not suitable for this work. Repairs are very difficult to carry out satisfactorily without lifting the rails, and it will be found impossible to relay the track without raising the level somewhat above the original levels.

In the first place the new rails will not lie upon the surface of the old concrete, owing to the inequalities of the old and new rail flanges, so that either packing or grouting will have to be resorted to in order to bed down the rails. This will, of course, lift the rail above its former level when new; and as the adjoining paving surface will have worn down, as subsequently described, at least half an inch, it is clear that there will be considerable expenditure upon repaving the sides of the road to bring them up to the new levels.

Experience on many systems indicates clearly that the proper procedure is to lay the rails first and the concrete afterwards, and that it is imperative that sufficient space should be left between the rails and the concrete to permit of the packing being reduced in thickness without affecting its efficiency when the track is relaid.

## CHAPTER II.

### CONCRETE MATERIALS.

The materials for track concrete have not always received the consideration to which they are entitled. In some instances a heterogeneous collection of building *débris*, consisting of soft brickbats, hard broken mortar, clinker from doubtful sources, and soft local sandstone, has been used, and the results may be more readily imagined than explained. Where the track is being constructed along a macadamised roadway formed with granite, whinstone, or limestone, no better concreting materials could be desired than the screened metal.

Some engineers have considered that the road metal was too good for concreting purposes, and it has been removed and utilised to coat other macadam roads and incidentally to reduce another department's expenditure, whilst old flags, bricks, and soft local stone, broken to a suitable size, have been substituted. Of all concretes, that for track foundations, not being of great thickness, should have the best and strongest materials for the aggregate. Old flags, bricks, and sandstone may be good enough for some concretes, but they are far from possessing sufficient strength to withstand the severe rolling stresses set up by modern heavy tramway services and, in addition, the ever-increasing weights of heavy motor and other vehicles. Such concretes are the first to fracture, owing to the aggregate not possessing the same strength as the matrix. It is equivalent to having a honeycombed foundation.

Water worn gravel is not so suitable as the hard broken metal of triangular shape. The pebbles are

smooth and rounded and the cement does not adhere so closely to them. They do not bed closely together, so that more cement is used than is actually required to produce a concrete of equal strength.

The question of sand for concreting purposes is a momentous one, for the concrete may be ruined by the use of an inferior or unsuitable sand. There is a great divergence of opinion as to the effect of loam in sand, one authority having stated that sand containing up to 20 per cent. of loam may be used without diminishing the strength of the concrete. This may or may not be the case, but there is not sufficient depth in track concrete to take any risks in this direction. In many inland towns the local pit and river sands contain such an excess of loam as to render them unfit for track concreting purposes, unless they have been thoroughly washed. The washing of sand is a troublesome and expensive operation, and the cost of the sand itself in such towns is very considerable. In Leeds the "clinker sand" prepared at the local refuse destructors is used for concreting purposes with excellent results. Only the hard blocks of hand-picked clinker from the ashpit refuse are used. These are crushed in rotary crushers having perforated pans for the required grades of the material. The table on page 15 shows the average strength of various concrete sands tested by the Leeds City Tramways staff.

The Leeds clinker sand has been used for concreting purposes for about five years, and has given the greatest satisfaction. It is uniform in quality and strength, and is about 50 per cent. cheaper than the ordinary local sand which, as will be seen in the following table, is of inferior strength. The screenings from the macadam should not be used instead of sand for the concrete foundations, as there is not always the opportunity for testing it. This material may, however,

be used for the floating, bedding, or grouting, or in such places where it is not subjected to carrying heavy loads.

Concrete test, 30 days. Size of specimen, 2 ft. 0 in. × 2 ft. 0 in. × 4 in. Concentrated load gradually applied.

| —— | Breaking weight. | Weight per cubic ft. sand. | |
|---|---|---|---|
| Local sand . . . . | 1,477 lbs. | 78 lbs. | Prepared with Portland cement in the proportion of 1—1. |
| Clokes Extension Co. (Leeds) screened minion (slag) . . | 4,770 ,, | 59 ,, | |
| Leeds Destructor clinker sand . | 5,123 ,, | 76 ,, | |
| Crushed gasworks retort lining . | 6,000 ,, | 74 ,, | |

Excellent results have been obtained in Leeds from the addition of "trass" to the aggregate. Trass, or puzzolana, is a ground rock of igneous origin, found largely in Germany and Italy. It is claimed for it that it creates a flexible crystal in the concrete, and tests certainly show that concrete made with trass as a constituent will bend considerably before breaking, which is an advantage on tramway tracks which are subjected to suddenly applied loads. Its chief feature is that it causes the concrete to set from the centre of the mass and effectually prevents the rapid setting of the outsides, which delays the setting of the whole and gives a false impression of strength. Concrete made with trass appears to take somewhat longer to set, but when it is hard enough to walk on it may be taken for granted that it is of the same degree of hardness throughout. Trass concretes are considerably stronger than ordinary concretes after a few months' setting; in fact a concrete of cement, trass, sand and broken stone 7 of stone, 1 trass, 2 sand to 1 cement can be made equal in strength to the ordinary 4—2—1 concretes.

In preparing and laying the concrete foundation it is

necessary that a skilled man should be in constant attendance on each banker, and every shovelful of concrete should be inspected as it is thrown into the bed. The concrete in the track must be well solidified and shovel-chopped by two "layers" standing in the bed; these men will shovel the material off the banker and lay it beneath the rails. These men must shape the bed and prevent the formation of voids by beating down the concrete. They must also maintain a uniform space beneath the rails for the packing. The material must be well rammed round the anchors so as to ensure a perfect hold in the concrete.

Concrete is frequently damaged before it has set, in several ways, *e.g.*, during the ordinary changes of temperature between day and night the rails will expand and contract, and if the anchors are fixed permanently they will be drawn through the soft concrete, causing local fractures which are sure to develop in course of time. The concrete must be carefully examined near all anchors, which should not be bolted on but attached by means of clips or wedges, so that they may be fitted in loosely, thus allowing a certain amount of movement to take place in the rail without disturbing the concrete, and all fractures must be carefully grouted with liquid cement, and the anchor wedges should not be driven home until the concrete is quite hard. Great care should be taken during the hot weather to prevent the concrete from setting on the surface too quickly, rapid setting being the cause of surface cracks which are likely to develop considerably.

On small jobs it may be possible to cover the new concrete with wet sacking, as recommended by some authorities, but it is obvious that the cost of providing sacking or matting would be prohibitive on a job of any size. Surface fractures may be prevented by damping the surface from time to time with a watering can.

Every effort must be made to prevent foot passengers and the workmen from walking on the concrete before it has become thoroughly set. Trampling on the new thin layer of concrete has a very bad effect, and in addition to retarding the setting, it is the cause of many cases of fracture, boot marks being clearly discernible on examining some fractured foundations.

Track concrete should not be laid when it is actually freezing, although it may be laid safely enough during the winter months if sufficient care is taken to cover up the concrete as soon as it begins to turn towards frost in the late afternoon. Thick bass mats and cement bags may be used for this purpose, provided they are not in contact with the concrete itself. A space of at least 3 in. should be kept between the cover and the concrete for the circulation of air. This may be done by placing planks on the tie-bars, and laying the mats across the top of the rails and planks.

## CHAPTER III.

### REPAIRS TO CONCRETE FOUNDATIONS.

A CONSIDERABLE amount of the expenditure on track maintenance is due to fractured foundations. It may have been observed that tracks require repairs at the same place time after time. In fact, given the same climatic conditions, the length of time the repaired portion will stand before it again requires attention may almost be calculated to a nicety. It is evident from the regularity of the repairs required at such places that there is a definite cause for the recurrence, and yet it is really painful to witness the endless patch, patch of the track at such places. The cause of the defect appears to be of little moment in the majority of cases, there is no investigation, the rails are simply said to be "springing," and the sunken or loose rails are automatically repaired in due course; the rails being repacked and the paving reinstated at very considerable expense. Much surprise is evinced that the rails work loose again in a very short time.

It is not until the track has been "patched" several times that any particular attention is given to the case, and as often as not the significance of the repeated repairs at the same place is lost sight of. Indeed, in many instances it is questionable whether it is really noticed; but in cases where the recurrence has been observed, it is seldom that any attempt is made to locate the source of the trouble. Usually recourse is made to anchoring, and when this fails likewise to remedy the defect the blame is laid upon the rigid method of construction. One authority on track construction has

even admitted his inability to lay a sound track in stating that the "setts should be laid with wide joints, so as to facilitate the repairs to the track which are inevitable."

And, still, if a little thought is brought to bear upon the matter, it should not be difficult to trace the cause of the defect. There is nearly always a simple solution for most phenomena, and so there is in this case. It may be taken for granted, where a track requires repairs from time to time at comparatively short intervals at the same place, that there is some defect in the foundation. The cause is simple, but it is not always easy to detect flaws in the concrete; indeed, in many cases the fractures are barely visible, but it is these innocent-looking fine hair fractures which cause the trouble, and, of course, they do not become any less, but develop rapidly. As has been stated previously, these fractures are either beneath the rail or near to it, and run longitudinally with it. In Leeds, on reconstruction work, it was not at first thought necessary to deal with these finer fractures, it being thought that they could not have much effect upon the track, and, in addition, it was considered that the new concrete which would have to be put in would in all probability fracture through having to carry the load before it had had sufficient time to set properly. So that on a few of the first renewals the worst fractures only were cut out, but careful observations were taken of the positions of a number of the more indefinite flaws, and it is worthy of note that at a later date repairs had to be executed at these very places. At the first sign of movement in the rails the paving was removed, and the concrete was excavated along the line of fracture. A trench, 18 in. wide, was excavated beneath the rail, and the rail was supported at frequent intervals by means of old fish plates and sole plates, laid transversely beneath the rail.

In cases where the length of the foundation to be repaired is of no great extent the concrete may be cut out and replaced without much trouble. The fracture may be beneath one rail only, and it is thus necessary

Fig. 3.—Partial Repairs to Concrete on Working Line.

only to excavate about 18 in. of the paving on each side of the rail, and the concrete beneath it. The rail should be bared for some little distance back on either end so as to permit of the rail being raised slightly. No special supports are required for this purpose; a few old

24 in. fish plates or sole plates will answer the purpose admirably if placed across the trench at about 5 ft. intervals, it only being necessary to prevent the deflecting rail from coming into contact with the new concrete.

It has been found advisable to insert a foot of concrete in such places prepared with quick-setting Portland cement, which is now easily obtained from the leading manufacturers. The concrete should be allowed at least two or three full days to set before the supports

Fig. 4.—Total Renewal of Concrete.

are withdrawn and the rail is repacked ; unless the subsoil is of a very treacherous nature, the above remedy will be found to be satisfactory, if properly executed.

The repairs to the concrete foundation during the reconstruction of the track are easily and readily carried out where the streets are wide and it is possible either to lay a temporary track or to operate a portion of a double line as a single track for the time being by inserting temporary loop ends. But it is not always possible to do this, and other expedients have to be devised. In

the case where the road is too narrow to permit the use of a temporary track and the car service is too important to be interfered with, the concrete may be relaid where necessary before the old rails are removed, as shown in Figs. 3 and 4. In these cases the paving has been removed and the rails have been raised above the original levels by the insertion of small channel irons, which act as bridges when the defective concrete has been removed. The whole of the work may thus be carried out whilst the track is in operation. The new concrete is inserted to within about an inch of the underside of the supports and is allowed two or three days to set, the old rails are then removed by the night gang and new rails are inserted the same night. The new track is packed the next day, and so the work proceeds without interrupting the car service. It might be imagined that such tracks will ultimately require much attention in the way of repairs; but such is not the case. Providing the concrete is carefully mixed and only the best cement and aggregate are used, and means are taken to prevent the new concrete from being trampled on, quite satisfactory results may be obtained.

## CHAPTER IV.

### TRACK DESIGN.

TAKEN as a whole, British tramway permanent way cannot be said to have been too well designed. In fact, there has been far too much of the "follow my leader" policy instead of close attention being given to the peculiar requirements of each system. An examination of the tramways in this country will reveal clearly that a design which has proved quite satisfactory in one district may fail completely in another locality. From this it is obvious that particular consideration should be bestowed upon the local conditions and service requirements. The more important of the local conditions are the sub-soil and the weight and density of the vehicular traffic, whilst the chief items to be taken into account in connection with the car service are the speed and weight of the cars and the frequency of the service.

In regard to the sub-soil, it may be mentioned that much of the trouble experienced with the track in many places is due to the action of sub-soil water beneath the concrete foundation. Where the ground is wet and clayey and does not drain readily, it is advisable to lay the concrete across the entire width of the track as shown in Figs. 5, and in places where the ground is water-logged it is necessary that the sub-soil should be drained. Figs. 6 show the method of draining a track laid in a roadway across a moor. This track had always caused a considerable amount of trouble, for in the first place the road was cut through the water-bearing strata and interfered with the natural watershed, with the

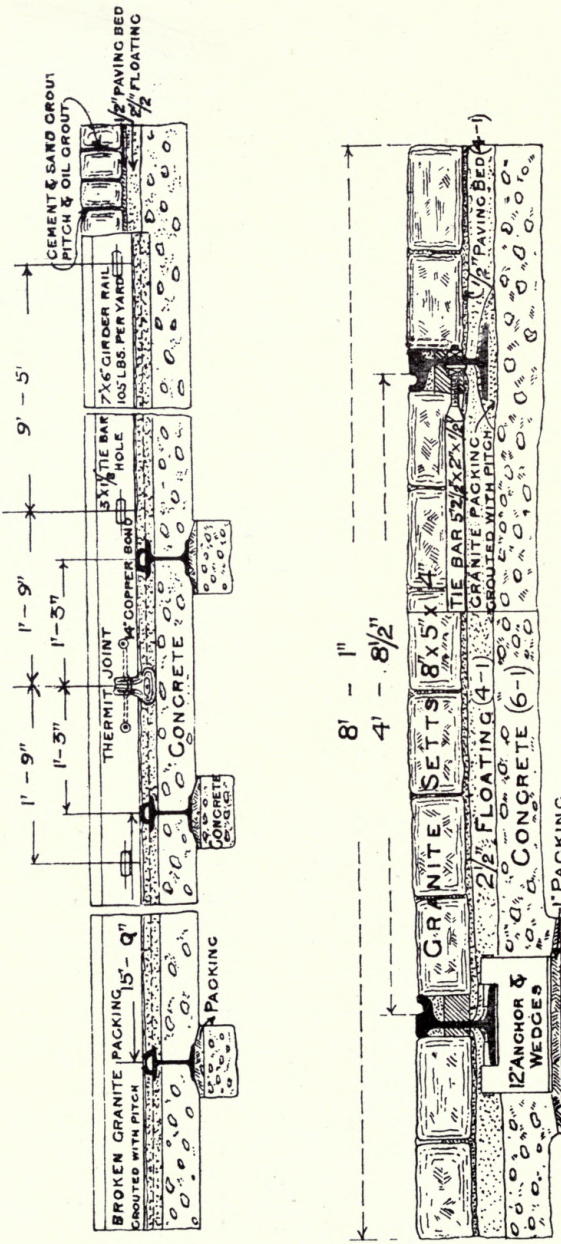



Fig. 5.—Details of Track Construction, Leeds Tramways.

result that the concrete became undermined and finally fractured. The track was relaid a second time with precisely the same results, and finally heroic measures were adopted, the entire track was taken up, a foot of the sub-soil (soft yellow clay) was removed, and a sub-soil drain was laid as shown in Fig. 6. A bed of engine ashes 12 in. thick was laid over the whole of the bottom of the trench, and the rails were relaid upon a 9 in. bed of concrete, and during the past seven years the expenditure upon the maintenance of this track, which carries a heavy high-speed service, has been negligible. On hard, self-draining foundations it is only necessary to lay a "stringer" of concrete beneath the rails as shown in Figs. 7 and 8, but such designs are only recommended where a judicious inspection of the foundation has shown it to be uniformly stable throughout.

The design shown in Fig. 7 is the standard method of construction of the Manchester Corporation Tramways, where very satisfactory results are obtained. In Manchester the concrete is laid across the full width of the track in wet or unstable sub-soils. Fig. 8 shows the cross-section of the Leeds to Guiseley line, which has been in service for six years under a fairly heavy high-speed service, and the expenditure on maintenance up to date is *nil*. It will be observed that the rails are anchored to the concrete, and there is a thin bed of concrete beneath the paving. There are several notable instances where this type of construction has been successful, but there are many instances of its failure, and in these days of the mechanical locomotion of road vehicles and the ever increasing weights and speeds of the same, unless there is absolute certainty as to the strength and dryness of the sub-soil, it is wise to be on the safe side and to lay the concrete across the entire track.

Where a track is to be laid upon a foundation which

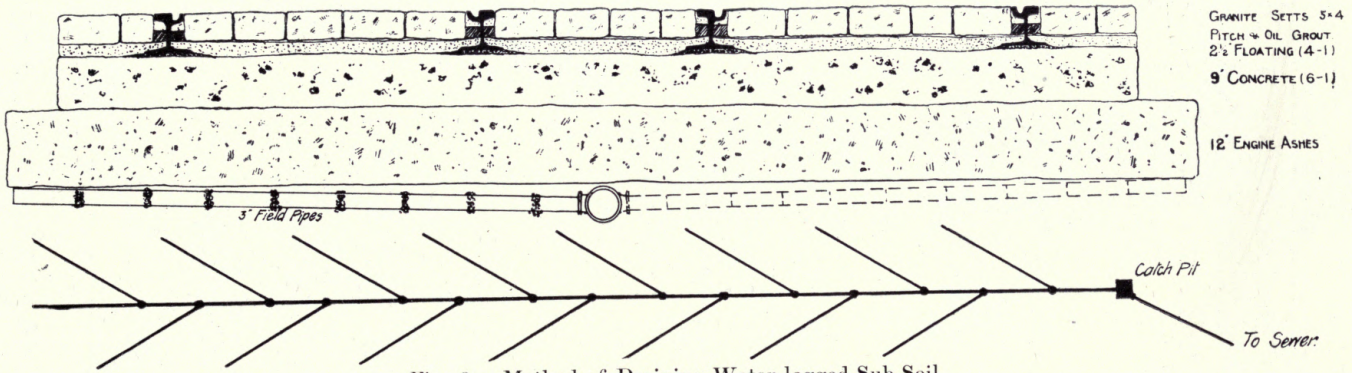



Fig. 6.—Method of Draining Water-logged Sub-Soil.

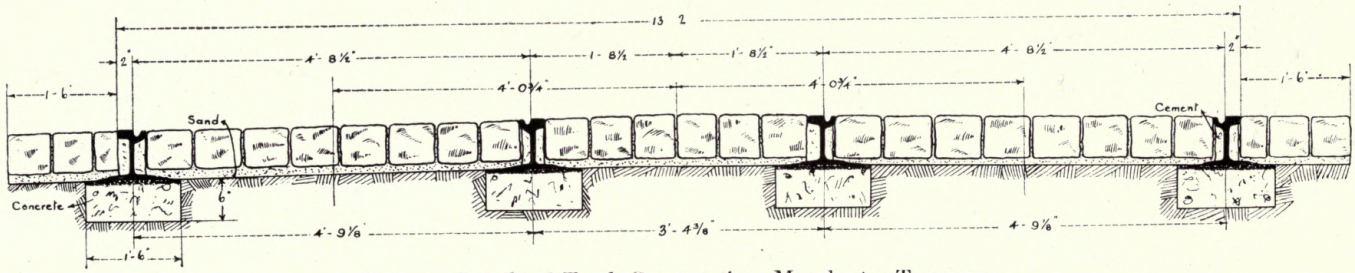



Fig. 7.—Details of Track Construction, Manchester Tramways.

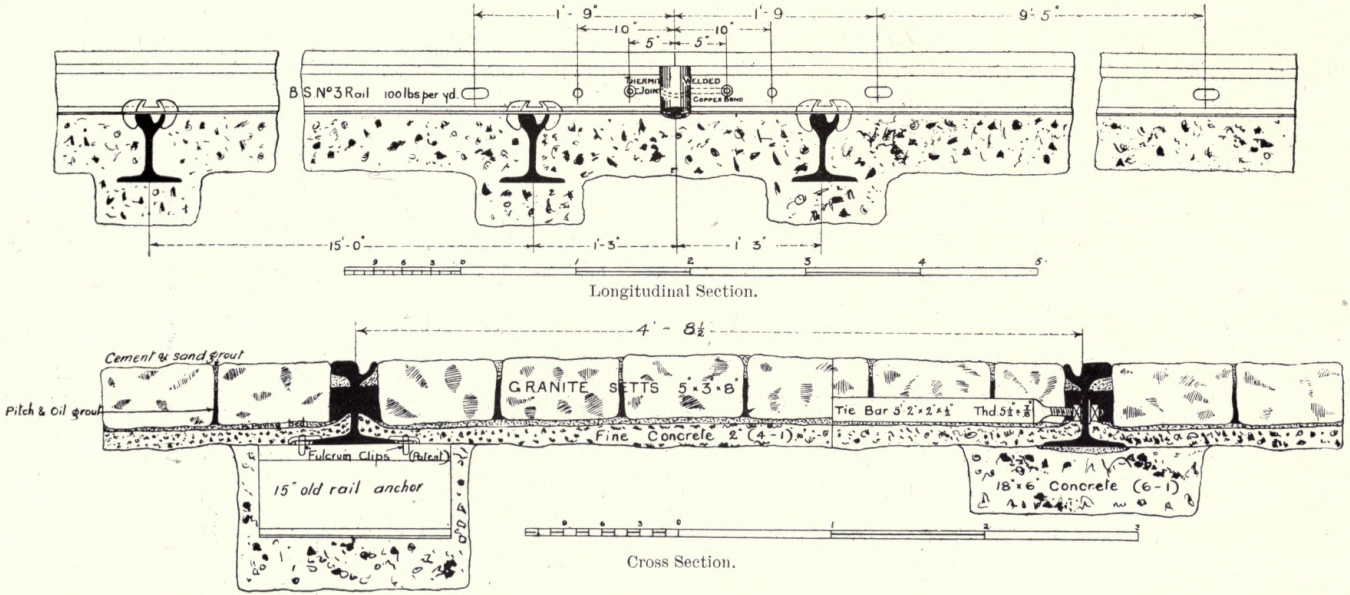



Fig. 8.—Details of Track Construction on Guiseley Route, Leeds Tramways.

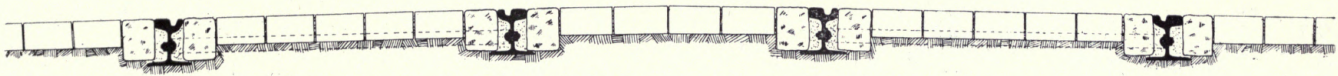
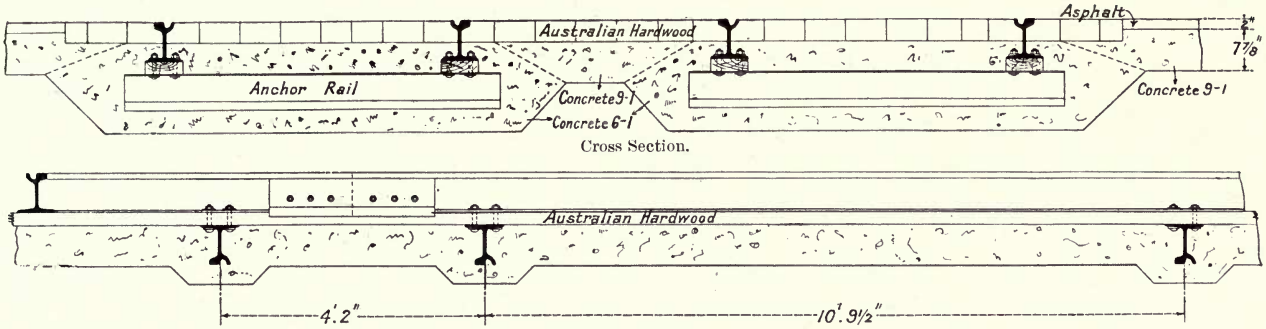


Fig. 9.—Details of Track Construction, The Hague Tramways.

is perfectly stable, and which drains itself immediately, it is obvious, of course, that there is no need for a concrete bed beneath the rails. But there are few places in this country where such ideal conditions prevail. Probably the most satisfactory foundation of this description is that on which The Hague tramway track is laid in Holland. At The Hague, concrete foundations have been dispensed with on all routes, with the exception of about a mile and a half of single track laid in asphalted streets. Fig. 9 shows the details of construction on this system. The rails, which are of the girder type (Phœnix section No 23c for straight track and section No. 23d for curves), are very similar in design to the British standard rails; they are "fished" with "continuous" rail joints, and are laid directly upon the sand foundation, being packed with fine sand also.

There are neither anchors nor sleepers, the rails being merely tied together at the usual intervals. The joints yield ever so slightly as the cars pass over them, but there is neither sign nor sound of "hammering"; the cars travel swiftly and silently over the rails, and generally the conditions are ideal.

The track is paved with either limestone setts or bricks according to the vehicular traffic, which is light. The paving, which is laid upon the sand sub-soil, without either pitch or cement grout (the joints being merely "racked" with fine sand), is in splendid condition, and the cost of maintenance, after more than six years in operation, is not more than £40 per mile of single track, equal to ·11*d.* per car-mile. The track is absolutely self-draining, the sand foundation is compact and well confined laterally, and the track is well above the water level. Fig. 10 shows the method of construction adopted in The Hague, where the streets are asphalted.




Cross Section.

Longitudinal Section.

Fig. 10.—Details of Track Construction, The Hague Tramways.

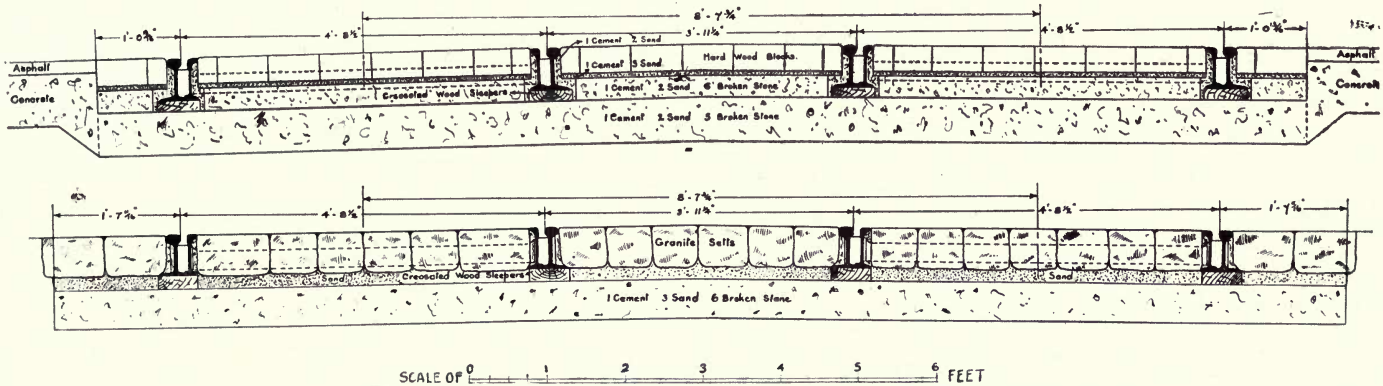



Fig. 11.—Details of Track Construction, Amsterdam Tramways.

The tracks in the asphalted streets, whilst lying evenly with the surface of the road, are noisier. The joints hammer, and there is a tendency to corrugate, which is not apparent on the flexible part of the track. As a proof of the suggestion that track design is largely influenced by local conditions, particularly in regard to sub-soil, it may be mentioned that the same method of construction, which has been so successful in The Hague after close upon seven years in operation, was tried in Amsterdam; but owing to the water-logged condition of the sub-soil the results were unsatisfactory, and the design of the track had to be altered and concrete foundations were introduced. Fig. 11 shows the details of the Amsterdam standard track designs for asphalted and paved streets, together with the details of the rail used (Fig. 11a).

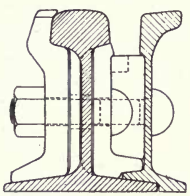


Fig. 11a.—Section of Rail, Amsterdam Tramways.

It will be observed that The Hague track is about as cheap a form of construction as it is possible to lay down, whilst the Amsterdam track is fairly expensive, on account of the concrete, sleepers and the extraordinarily heavy rail used.

Fig. 12 shows the track designed by Mr. A. E. White, M.I.C.E., for the Hull City Tramways. This track was designed to give "exceptionally smooth riding," and it may be fairly said to have achieved its object. In passing, it is interesting to note that, notwithstanding the good results which have been obtained on this system, the rails have not escaped the modern scourge of rail corrugation.

The following description of the Hull track, which appeared in the issue of *The Tramway and Railway World* of August 10, 1899, explains clearly the details of construction:—

"Mr. White and his associates desired to secure not

only a durable form of construction, but a track which will give exceptionally smooth riding. With this end in view, they have departed from the customary plan of laying the rails direct upon the concrete foundation, and have interposed longitudinal sleepers of creosoted redwood, 4 in. deep by 7 in. wide, upon which the rails rest. The concrete foundation upon which the paving is laid is, however, carried down under the sleepers, and the rails are bolted down through the sleepers to the under side of the concrete at intervals of 3 ft. 6 in. The roadway was excavated to a depth of 12 in., which, under the rails, was increased to 17 in. to make room for the sleepers. When the excavation was complete, the sleepers were packed upon bricks at the proper level,

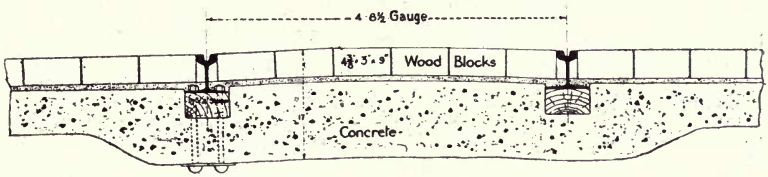



Fig. 12.—Details of Track Construction, Hull Tramways.

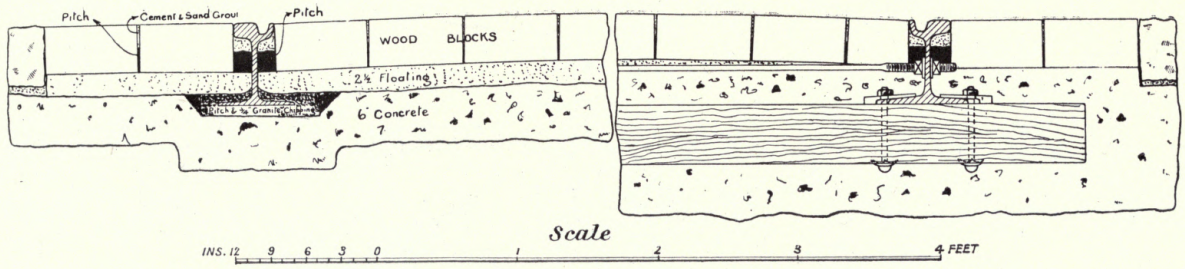
and were clamped tight under the rails and secured to them by dogs. The holding-down bolts and washers were placed in position and, after the rails were carefully lined up, the foundation was put in, special care being taken to pack it tight under the sleepers. When the concrete had set thoroughly, the holding-down bolts, which measure 14 in. in length, were tightened up ; rail, sleeper, and concrete being thus firmly bound together. The rails weigh 94 lb. per yard and are 60 ft. in length. They have a centre groove which is $\frac{15}{16}$ in. in width, the head measuring $3\frac{1}{4}$ in. overall. The objects sought by the adoption of the centre groove are (1) to secure even wear on both sides of the rails, thus avoiding the projecting lip which, as the rail wears down, is often a serious annoyance to street traffic ; (2) to secure con-

tinuous support for the car wheels when passing the rail joints, which are splayed, and when passing joints and crossings; and (3) to increase the wearing surface of the head, thus adding to the life of the rails."

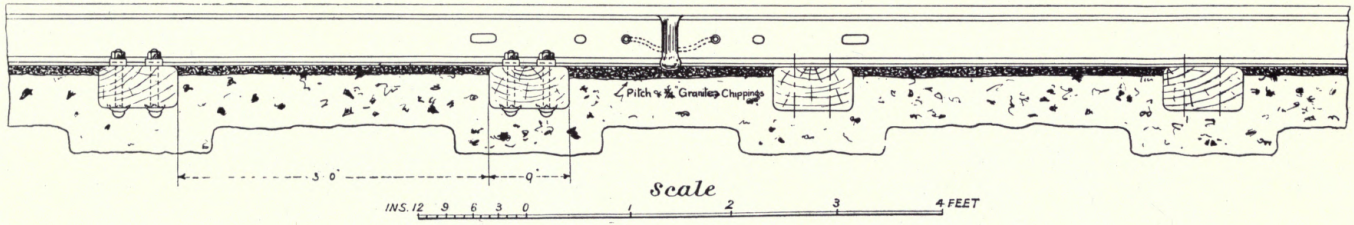
It would appear that this method of construction, which was adopted on very flat routes, would not render itself very easy of application on a hilly system with the undulating and tortuous tracks which are so common in many parts of the country. One would imagine that a considerable amount of difficulty would be experienced in bedding and bending the rails and sleepers together. Again, the same difficulty will be experienced in regard to renewals, as has been mentioned previously; unless the sleepers are reduced in thickness or replaced with shallower sleepers, a considerable amount of repaving of the sides will have to be done.

Transverse sleeper tracks have been laid in several towns, and undoubtedly they give satisfactory results. The sleepers act as anchors where the tracks are floated, and as they are closer together than the usual track anchors they afford a very definite anchorage for the rails and prevent "hogging." Such tracks cannot be said to be flexible tracks in any way; they cannot yield in any direction, but the sleepers may absorb a certain amount of vibration.

The disadvantages are the additional cost of the sleepers and bolts (see Fig. 13), and the fact that where this method of construction has been adopted the rail is packed between the sleepers with hard materials, no advantage being gained from the resiliency of the sleepers. In other words, if the sleepers are 3 ft. apart, from side to side, then three parts of the rail is bearing upon hard concrete and the other part upon timber. If it is desired to lay a track upon transverse timber sleepers, the best results, by far, will be obtained if the rails are packed between the sleepers with pitch and




Cross Sections.




Longitudinal Section

Fig. 13.—Details of Track Construction, Belle Vue Road Section, Leeds Tramways.

granite, as shown in Fig. 13. In regard to the weight and density of the vehicular traffic, these are factors having a direct bearing upon the design of the track, particularly in our busy industrial centres, where extraordinarily heavy loads of goods are hauled by mechanical power along and across the tracks. These heavy loads, it must be remembered, are not rolling smoothly along the rails, but are jolting over the rough surface of the paving, and slipping on and off the rails with deleterious effect.

Figs. 14, 15, 16, and 17 show the effects of the ordinary vehicular traffic upon the rails and paving in a busy city. Fig. 16 shows that part of the rail tread has been worn down through the constant use of the rails by the street traffic, and it may be mentioned that the particular rail shown in the illustration has been laid in a track for over six years, which has not yet been operated by the tramway service.

Fig. 17 indicates cheek wear due to the same cause. From these examples, which are by no means uncommon instances of the wear due to vehicular traffic, it will be seen that considerable attention must be paid to the effect of this traffic upon the foundation, the rails, and the paving.

The question of the tramcar traffic is of course most important, and requires close attention; but it is a mistake to suppose that the actual weight of the car and the traffic density is the all-important factor in rail and track wear. The tracks which suffer the most and the rails that wear the quickest are those which bear the high-speed traffic. Observations have revealed that, in places where the speeds are necessarily slow, over 60 million tons of tramway traffic have been carried by rails similar in design to rails on other tracks, carrying a fast service, which have become battered and worn out after carrying 10 million tons of traffic. If it is

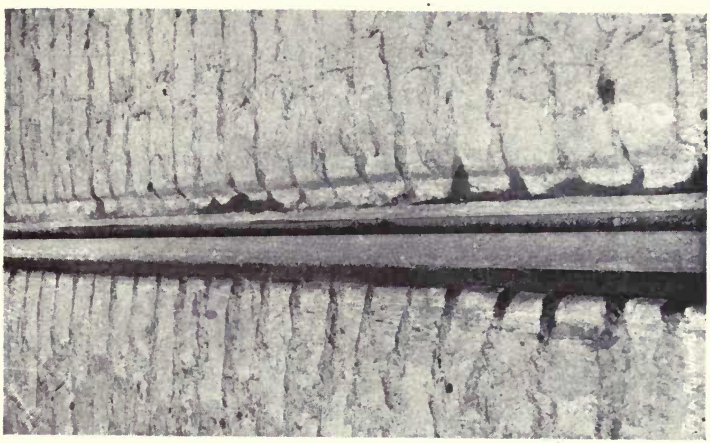


Fig. 15.

Fig. 14.
Effect of Ordinary Street Traffic on Track Paving.

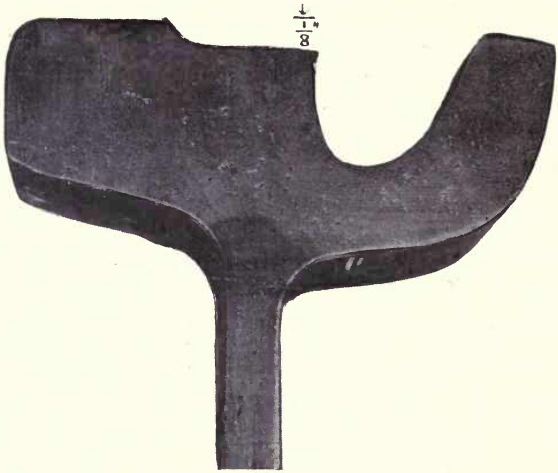



Fig. 16.—Head of Rail worn by Street Traffic alone.

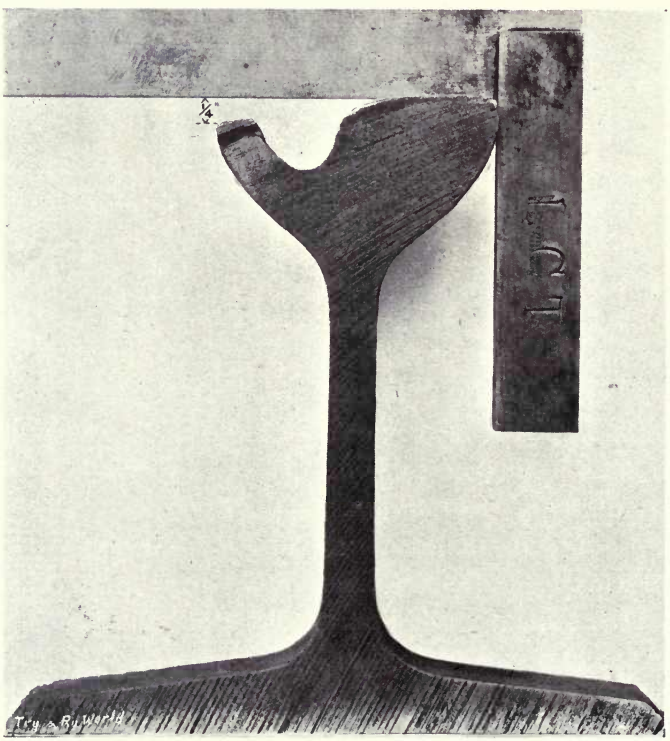



Fig. 17.—Cheek Wear due to Street Traffic.

desired to obtain a long life for the rails and track, particular attention must be paid to the question of the speed of the cars and to the design and composition of the rails. The importance of the effect of speed as a factor in rail design does not appear to have received that consideration to which it is entitled, and some engineers and the British Engineering Standards Committee favour a lighter section rail for suburban traffic where the speeds are considerably above those attained in the busy thoroughfares.

## CHAPTER V.

### RAIL PACKING.

One of the most important operations in tramway track construction and maintenance is the packing of the rails. Provided the concrete foundation is sound, and apart from the question of rail joints, there is not the slightest doubt that the majority of track maintenance troubles are due to defective rail packing. Such defects are caused in several ways. In the first place, the rails may not have been properly and systematically packed when the track was laid; secondly, the rails may have been well packed at the time, but between the packing operation and being paved in the rails may have been disturbed either through carelessness or by the expansion and contraction of the exposed rails; and thirdly, the materials used may not have been of suitable quality or hardness, etc.

To obtain satisfactory rail packing the space between the rail base and the surface of the concrete should not be less than 1 in., nor greater than 2 in. On a new tramway track the rails should not have less than $1\frac{1}{2}$ in. of packing between their flanges and the surface of the subjacent concrete, for when the tracks are relaid it will be generally found that the adjoining roadway has worn down at the same rate or faster than the track surface, and as probably at least half an inch will have been worn off the rails and the paving setts, it is obvious that unless some provision is made for lowering the new surface of the track it will be above the level of the rest of the roadway, and there will be a considerable amount of the sides of the road to repave or macadamise; so

with a view to avoiding considerable additional expenditure it is recommended that provision should be made for 1½ in. of packing, so that at the first renewal this thickness may be reduced to one inch, and the track lowered to the same level as the sides of the road. Of course there is no necessity to make provision for the second renewal of the track, as the paving of the sides of the roadway will either have been relaid, or will be ready for relaying by that time. The rails should be packed as soon as the concrete has set sufficiently hard to bear the weight of men. There is a considerable difference of opinion as to the right material to use for rail packing or bedding. At the present time there are three methods of rail packing.

First of all, and most general, is the method of packing with cement and chippings ; secondly, packing with pitch and chippings ; and thirdly, the rails have been bedded upon shallow longitudinal timber sleepers, in lieu of the ordinary packing. It would be invidious to compare the merits or demerits of each system ; let it suffice that good results may be obtained from each, provided that the work is properly and skilfully executed.

In regard to packing with cement and chippings, it will be found that ⅜ in. chippings, free from dust, mixed with cement, and just moistened, in the proportion of 2½—1, will give the best results. The composition should be shovel packed beneath the rails from both sides with square mouthed shovels, so as to ensure its being spread entirely under the whole of the rail flange. It should then be carefully beaten solid by means of beater picks. The packing edge of these picks should be bull-nosed, and should be about 2½ in. wide and ¾ in. thick. Packing is executed in the following manner : Six men are usually " set on " to pack a length of rail, two with shovels and four with beaters, and they work from

opposite sides, as shown in Fig. 18. Each man places one foot against the edge of the rail flange whilst packing from the other side, so as to prevent the packing from being forced out by the "beaters." The method of beating should consist of a number of short half-arm strokes until the packing is quite hard and unyielding. The two front men should beat in all the material required and the two rear men should follow inch by inch in their traces and finally consolidate the material. The spare material should then be neatly sloped off at the sides of the rail and damped sufficiently to set quickly and prevent the packing from being disturbed.

Great care must be taken that the operation of packing the rails does not wedge the rail up beyond the required surface levels. It will be readily seen that unless the work is well supervised there is a danger of the rails being "hogged" through over-beating, either throughout their length or between the anchors. Care must also be taken, in packing successive lengths of rails, to prevent the rails from being lifted at the point where one length of packing joins another. It is evident that the slightest amount of overbeating will raise the rail above the adjoining former packing, and this will become a weak place in the track and a source of trouble afterwards. The rails when packed should be perfectly solid, and should not show the slightest signs of vibration when struck on the head with a hammer; a skilled foreman will readily detect the slightest signs of looseness by giving the side of the rail head a sharp kick with the boot heel whilst standing on the rail. The foreman platelayer should examine the surfacing by going down on his knees from time to time and sighting along the rails—any signs of over-beating will be at once detected in the undulations of the rail surface.

It is almost impossible to secure a rigid track if the rails are packed, say, more than one rail length in front

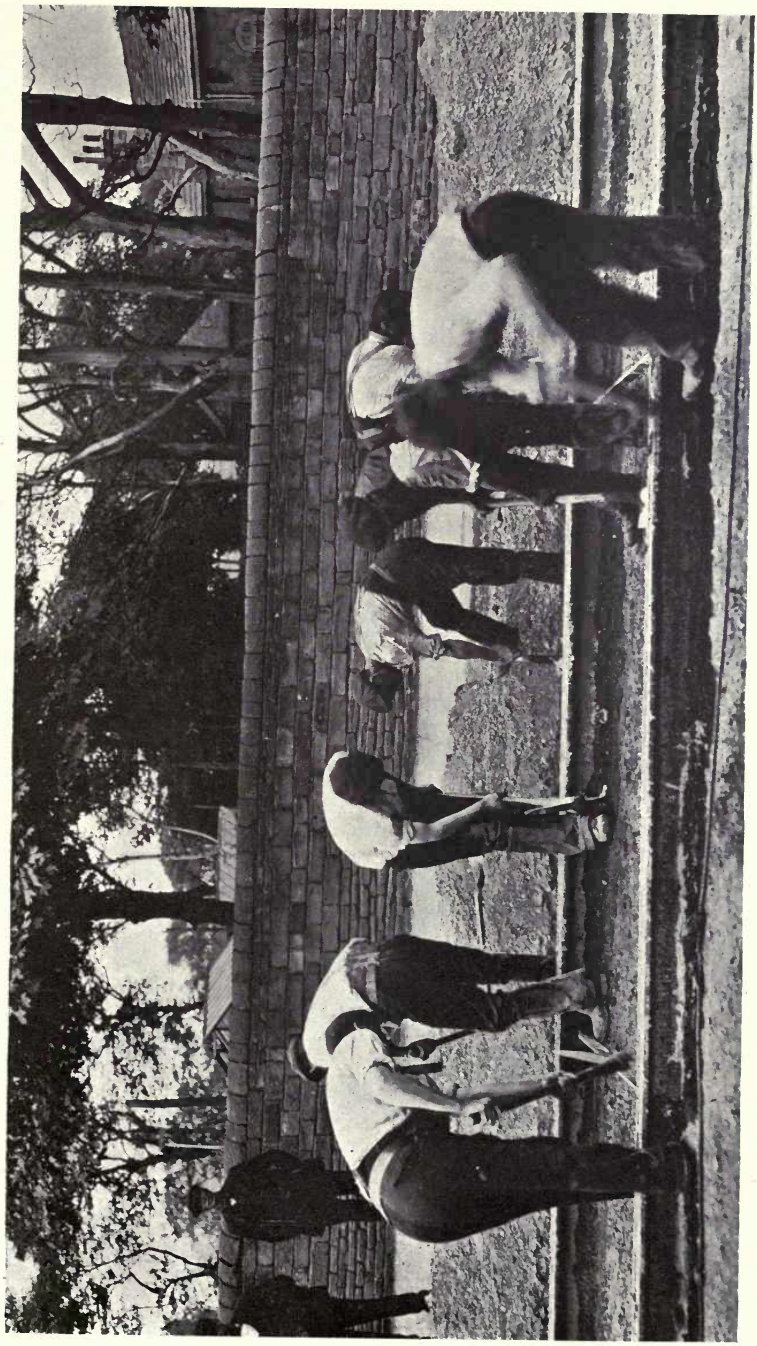


Fig. 18.—Packing the Rails with Cement and Granite Chippings.

of the floating, or one rail length in front of the paving if the track is not floated. The rails are continually expanding and contracting, and the rough undersides of the rails will abrade the surface of the packing, spoiling the contact between the two, however slight the movement, and this is when close supervision must be exercised. The rails must be sounded time after time before they are paved in ; it is not sufficient for them to be examined once and passed as being satisfactory. They may be, and undoubtedly are, quite sound at the time, but inall probability the rail will move slightly, even in the short length mentioned. It is therefore absolutely necessary that a skilled man should carefully sound the rail between each tie-bar or anchor, immediately in front of the floating stage and paving, and if there is the slightest sign of vibration all other work must be suspended until the rail has been properly packed again.

The rails will continue to expand and contract even after the floating has been laid and the anchors have been tightened up. It is therefore imperative that the rails should be paved in as soon as possible, but by far the best precaution to take is to arrange the strength of the packing gangs so that their rate of progress does not exceed that of the paving gang, or that of the floating gang where the tracks are floated. By thus regulating the speed of the work, and by arranging that the packing gang have one rail length start, the same distance will be maintained between the gangs. This method will not in any way retard the work, and if it is desired to accelerate the rate of progress, all that is required is the strengthening of each gang. Many tracks have suffered from having too long a length of rails packed and exposed to the variations of temperature.

One case in particular may be mentioned which is

typical. Nearly three-quarters of a mile of roadway was open at one time, causing great inconvenience to the vehicular traffic, and there was a distance of nearly 800 yards between the last finished rails and the paving works. Two-thirds of the rails had been packed, inspected, and passed as being perfect, and for some considerable time these packed rails were subjected to changes of temperature varying between 62 deg. Fahr. and 92 deg. Fahr. The rails alternately elongated and contracted, grinding away the surface of the packing, and they were finally paved in in this condition. It is not surprising, therefore, that great expense is incurred in maintaining this track, and that the expenditure commenced simultaneously with the car service. It may be claimed that this is an exceptional case, and that many tracks have suffered in a similar manner where greater precautions have been taken, but there have been many such cases, particularly in the case of floated tracks where the paving has been kept many hundreds of yards behind the packing by reason of the time required for the floating to set. Too much care cannot be taken over the packing of the rails and their subsequent examination ; under the ordinary changes of temperature rails will rise slightly from their beds between anchors spaced 9 ft. apart. This rule should be definite and enforced to a degree, that no rails should be paved in which show the slightest indication of unsoundness, and it must be remembered that many of these indications are not discernible to the layman, and require a practical man to detect them.

Rails are frequently disturbed by some external cause such as the unloading of granite setts. It is quite a common sight to see half a dozen carts tipped at a time, and time after time, so that the entire load is shot against the sides of the rails. The setts should be

tipped at the side and thrown by hand into the bed, as it must be obvious to anyone with a grain of common sense that the rails and bedding are not improved by such treatment. It is frequently necessary to arrange for temporary level crossings for ordinary vehicular traffic before the track is paved in. These are generally formed by laying sleepers longitudinally with the rails for the vehicles to cross the track. The rails are thus subjected to disturbing treatment, and should be carefully examined afterwards for unsoundness, and repacked where necessary.

### Pitch and Tar Packing.

The enormous amount of skill and capital which is being devoted to the production of standard compounds, for highway purposes, from the distillation of coal tar, indicates that the solution of the road problem is likely to depend upon the rational application of scientifically prepared tar and pitch compositions, and up to the present there are no signs of any material being substituted which would combine the qualities of cheapness, resiliency and proof against water.

Until quite recently such compositions have been crudely prepared to rules of thumb, handed down from one ancient "tar-boiler" to another as a kind of "black magic," but the demand for reliable mixtures of this description has brought in its train scientific instruments and knowledge derived from the application of the same.

Notwithstanding the many failures of tarred roads which have been recorded during the past decade, there have been some successful achievements, due to the skill and attention of the engineers responsible for the work, and now the satisfactory construction of such roads is more frequent. At the same time roads of this description are being made daily which are fore-

doomed to failure on account of either the unsuitability of the materials used, the faulty preparation or the careless application of the same.

The observation of temperatures and the consistency of the various materials employed has in many cases been either neglected or unconsidered. It is not the writer's intention to deal with the construction of tar macadam roads, as such are without the scope of this treatise, but to draw attention to the use of tar or pitch-treated packing beneath tramway rails.

Tar packing, in one form or other, has been used to a limited extent on tramways since their inception, but until quite recently, say within the last five years or so, it has not been used with any measure of success on electric tramways. As previously stated the quality, preparation and application of the materials has been responsible for the failure. Many track engineers have had faith in the tar treatment of rail packing and have, with noteworthy persistence, continued extensive experiments, with the result that this material can now be made to withstand the destructive effects of electric traction in a satisfactory manner.

In nearly all the earlier failures there were indications here and there that the treated packing was capable of supporting the super-imposed rolling load, and as the recurrence of phenomena establishes a law, it was evident that the difficulty was surmountable.

The principal difficulty lay in obtaining a tar composition of uniform consistency and in the lack of knowledge of the various materials which is necessary if the requisite conditions are to be fulfilled. Much useful data was obtained by the experimenters which led to a decided improvement in the matrix, but for some time the results left much to be desired. Despite the care which was taken in the preparation of the matrix, examination of the packing under observation revealed

that the tar was soft in some places and too brittle in others. From this it was deduced that before satisfactory results could be obtained the materials would have to be in accordance with a standard specification and prepared to within narrow limits of temperature.

In regard to the application of the matrix this, in the first place, was applied to small chippings, which after being coated, were beaten or packed beneath the rails in the usual manner; but it has since been found that the only satisfactory way to obtain durable tar packing is to pack the chippings, which should be somewhat cubical in shape, perfectly clean and dry and free from dust, beneath the rails before the application of the tar or composition. The method of application is as follows:—After the dry chippings have been solidly packed under the rails in the usual manner, dry sand moulds are laid alongside the rail flanges as shown in Fig. 19, and the matrix is poured in from one side in the form of grout. As soon as the grout percolates through to the other side, this side is "flushed up" in a similar manner, and both sides of the rail base are covered with the composition to the depth of about an inch or so, thus forming an efficient waterproof (Fig. 20).

The testing and preparation of the materials may be carried out in accordance with the following specification, which will be found to give satisfactory results; but it must be noted that the particular standard of toughness of the prepared matrix will depend somewhat upon the nature and shape of the stone used and to a certain extent upon the climatic conditions and also upon the requirements of the engineer. The three qualities shown below are merely intended as a guide, and it will be evident that they are capable of modification.

*Pitch.*—The pitch used for this purpose shall be of

the quality known as "medium soft" and shall have a fusing point at 170 deg. Fahr. (with an allowance of 5 deg. under or over). The fusing point shall be ascertained in the following manner:—½ inch cubes of the "medium soft" pitch shall be cut or moulded

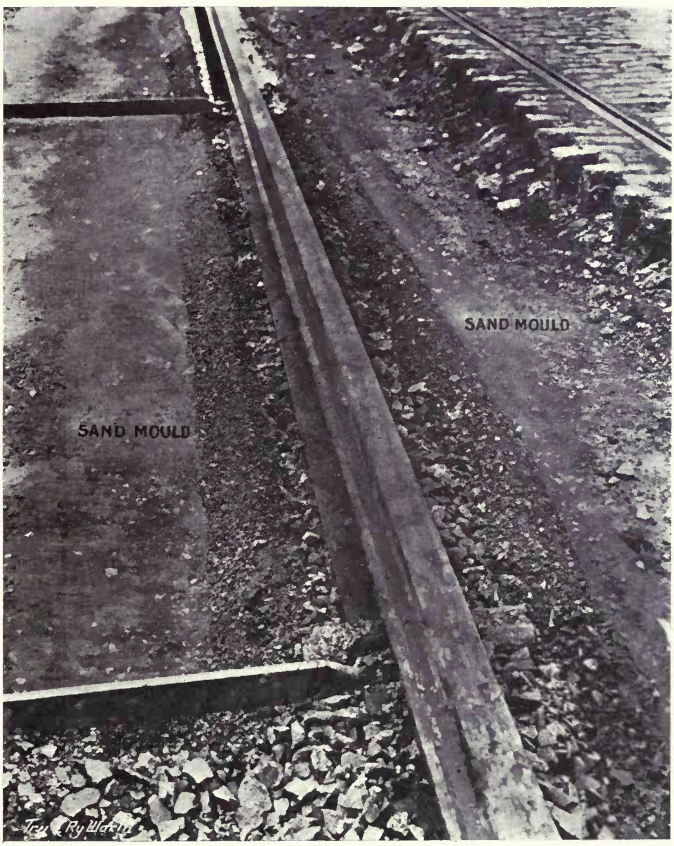



Fig. 19.—Rails prepared for Pitch and Granite Packing.

The rails have been packed with dry granite chippings, and a sand mould has been formed at each side of the rail prior to the running of the pitch and oil grout.

and then brought to a temperature of 60 deg., in water. Next heat the end of a piece of wire and pass it into a cube so as to allow of its being suspended in water at 60 deg. Fahr., with a thermometer bulb close to but

not touching the cube. The temperature should then be raised at the rate of several degrees per minute, until the cube falls off the wire. The temperature at

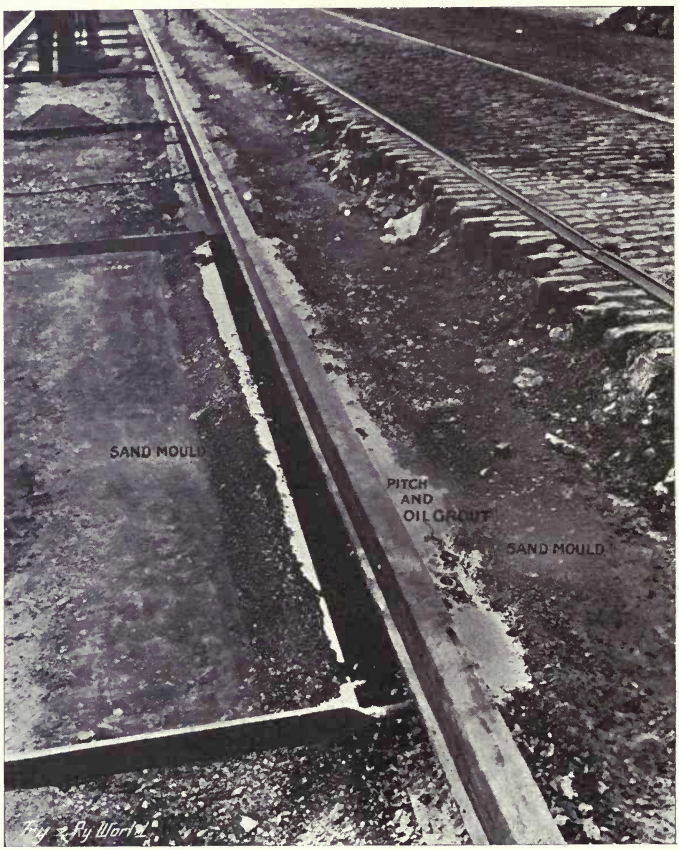



Fig. 20.—The same Rail after the Running of Pitch and Oil Grout.

The pitch composition has been flushed well up above the level of the rail flanges.

which the cube falls off the wire will be the fusing point.

*Prepared Tar.*—The prepared tar used in preparing the matrix shall be of such a quality as to record a consistency of 7—10 seconds, at a temperature 77 deg. Fahr., by Hutchinson's viscosity gauge.

### Pitch Mixtures.

*Mixing.*—The pitch shall be melted first, and raised to a temperature of 220 deg. Fahr. The prepared tar or oil shall then be raised to a temperature of 160 deg. Fahr. and then added to the melted pitch, the whole being *thoroughly* mixed.

The fusing point of the mixture should not be below 104 deg. Fahr. The following samples of prepared matrix will be found to cover most of the ordinary requirements of the track engineer.

| No. 1 (soft). | No. 2 (medium). | No. 3 (tough). |
|---|---|---|
| 5 parts pitch. | 6 parts pitch. | 7 parts pitch. |
| 3 parts Tarvia or other prepared tar. | 3 parts Tarvia or other prepared tar. | 3 parts Tarvia or other prepared tar. |

It is obvious that special instruments must be used in the preparation of these compositions, the most essential being thermometers of the type shown in Fig. 21, which represents a Hutchinson protected thermometer specially designed for taking the temperature of tar, pitch, asphalt, stone, sand, etc., in bulk, the special feature of this instrument being that it is graduated from 100 to 500 deg. Fahr. and is protected by a revolving metal cover which protects the scale and mercury tube. In order to ascertain the viscosity of tars a Hutchinson viscosity gauge is probably the most suitable instrument for the present purpose. This is shown in Fig. 22. This instrument is an instrument of precision, made of German silver, and will give accurate results; it is used in the following manner:— The entire length of the instrument is nine inches and the test is based upon the speed with which it sinks into the liquid under test, the observations being made on the time taken in sinking from the collar A to the collar B. This instrument, which is the invention of Mr. J. Hutchinson, 11, Tothill Street, Westminster, is

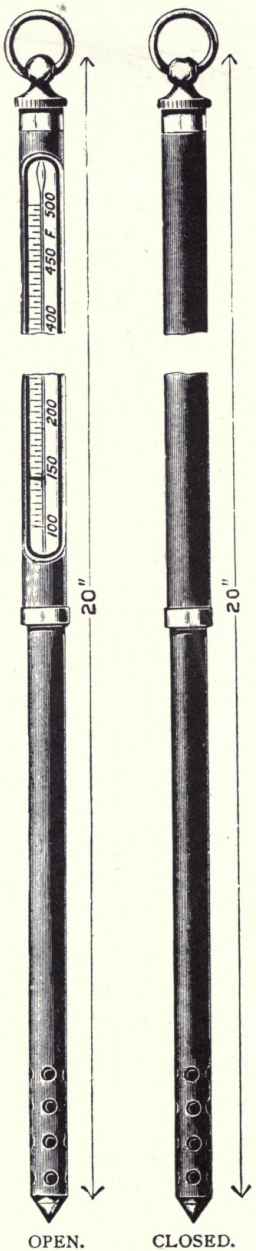



Fig. 21.

Hutchinson's Protected Thermometer.

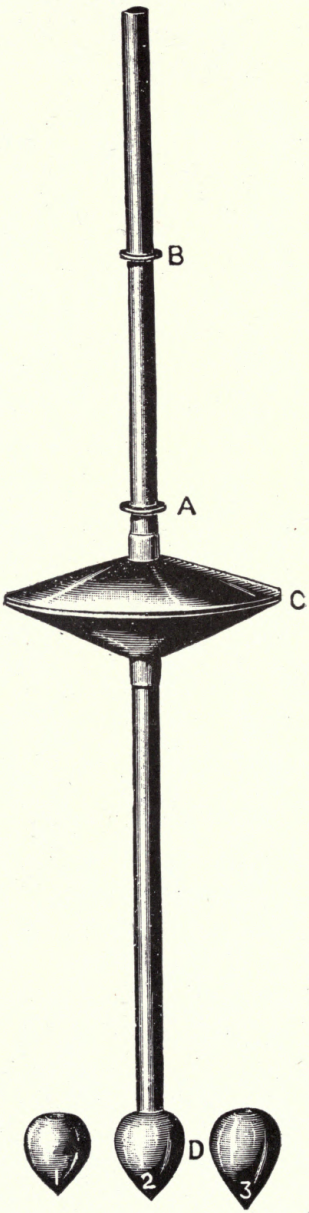



Fig. 22.

Hutchinson's Viscosity Gauge.

provided with various poises and may be used for the determination of the consistency of all kinds of liquids.

In conclusion the writer recommends that, where possible, the best practice, for tramway purposes, in order to obtain uniformity of composition of this tar or pitch matrix is to have it prepared in the central depot, and sent out for use on the works either in small boilers that only require keeping to a given heat ; or where large quantities of the material are required, the previously prepared composition, having been run off into moulds and allowed to cool off, may be sent out in this manner under cover and merely raised up to the required temperature on the works.

It will be seen that this method ensures uniformity of composition and reduces the responsibility of the "tar-boiler" to merely taking the temperature of the contents of the pan.

It is sometimes found that in an otherwise perfect track there are slight signs of movement in the rails in places, and on opening out the paving it is found that the concrete and packing are in perfect condition ; but there is the very faintest suspicion of movement in the rails.

This is generally a sign that either the rail has never been properly packed or it has lifted ever so slightly before being paved in ; in such a case it is a mistake to knock out the sound packing and repack the rail. A very good plan is to raise the rail the merest trifle with very thin steel wedges, dry the underside of the rail base with a blow lamp, and finally grout beneath the rail with hot well-tempered prepared pitch, after which the wedges should be immediately withdrawn, thus letting the rail down to its bed. This method has proved very satisfactory in many cases where there has only been the slightest trace of motion, and it has effectually prevented the spread of loose rails and paving. Pitch

packing on both new and old tracks has this advantage, that it prevents to a certain extent the evil effects caused by raising the rails slightly above the adjoining packing, the hot fluid pitch generally finding its way into any interstices caused in this manner.

The greatest care should be taken to prevent this evil, for an evil it is, and one generally at the root of patching troubles, of raising the rail above the general levels, whatever the method of packing. Regarding the repairs to existing tracks, one or two suggestions may be appropriate in this chapter, as the work is principally packing, viz.: In raising and repacking a loose or sunken rail it is necessary that the damaged and broken old packing should be entirely removed, and the springing of the rail traced to its source. It is false economy to clear away the old packing and repack in the old places, leaving the rest because of the expense or because it is not so very bad. If this is done, the rails, being slightly loose on either side of the recently repaired portion, will gradually become worse, the defect will spread along the rail, and very soon the whole of the work will have to be done again. Again, great care must be taken in repacking the portion under repair so as not to raise the rail above the general level, for if this occurs the portions of the rail on either side of the length being repaired will be raised slightly from the bed, and there will, in the near future, be two additional weak places. These are apparently two simple instances, but the neglect of them is fraught with much danger to the stability of the track, and considerable expense will be incurred. They are very difficult to detect and keep under supervision. This has also been known to have been taken advantage of by unscrupulous workmen, for securing the permanency of their employment.

The aggregate for packing should be the hardest and toughest procurable, and should be either of granite

chippings or steel works slag; good results have been obtained from both. For cement packing the size should not be less than $\frac{3}{8}$ in. or larger than $\frac{1}{2}$ in., the chippings should be triangular in shape, free from dust, and in the case of the slag, it should be well weathered and as free from sulphur as possible. For pitch packing it is recommended that chippings should not be less than $\frac{1}{2}$ in. or larger than 1 in. where provision is made for $1\frac{1}{2}$ in. of packing.

The smaller riddlings from the macadam, small freestone and limestone chippings, and small pebbles have been used on some tracks, but they are altogether unsuitable, and their use cannot be too strongly condemned. Nothing but the best, cleanest, and strongest materials will serve this purpose. On the Continent and on at least two systems in this country longitudinal timber sleepers have been laid between the rails and the concrete, as shown in Figs. 11 and 12, in lieu of the ordinary packing, and there can be no doubt that very good results have been obtained, but it is erroneous to describe this as a flexible form of construction; there is no real flexibility, but very considerable advantage is gained through the absorption of vibration by the sleepers.

### Floating.

The majority of the more recently constructed tracks have had a layer of fine strong concrete, to which the name of "floating" has been given, laid over the rail flanges, and across the entire track as shown in Fig. 5 and also in Fig. 23, with the idea of attaining the following objects, viz., first, the continuous anchoring of the rail; secondly, the waterproofing of the rail base; and thirdly, the reduction of the cost of the paving by permitting the use of a shallower sett.

This floating is generally mixed wet in the proportion of about four of sand, shingle, slag, or approved macadam screenings, to one of cement. It is spread by means of wooden templates laid across the rails, and

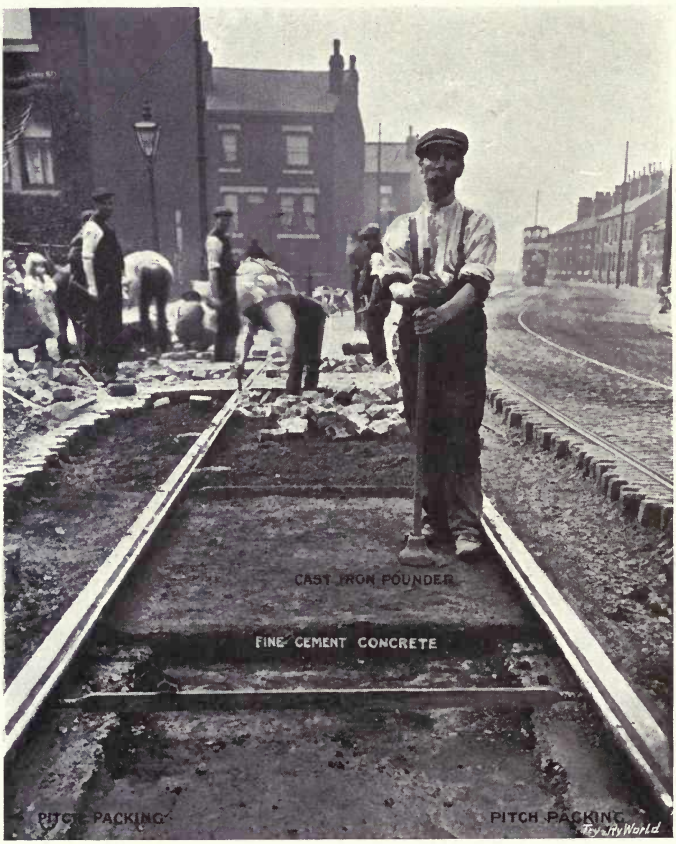



Fig. 23.—Method of "Floating" Fine Strong Concrete above Foundations and the Rail Flanges.
It will be noticed that the rails have been packed with pitch and granite. The pounder used is also shown.

is finished off to a true surface with plasterers' floats. When properly executed there is no doubt that it affords the additional anchorage and water sealing of the rail base; but there is one great disadvantage when it is applied wet as described above, in that it takes

two or three days to set sufficiently hard to bear the weight of the paviors and the ramming, and consequently a considerable length of track and roadway is open without any works being in progress, which, besides being a great inconvenience to the general public, has a deleterious effect upon the track. The rails are exposed to the variations of temperature, and are liable to lift slightly from the packing between the anchors. This cannot be noticed very well at the time, as the wet floating does not crack. By far the best method of floating, and one causing the least inconvenience to the public, and at the same time expediting the progress of the work, is to pound in the composition in a moist condition. By moist is meant that there only be sufficient water to damp the mixture, which should be laid in the bed and carefully and systematically rammed or "punned" with heavy cast-iron beaters, as shown in Fig. 23, until it is perfectly solid, care being taken that the required levels are obtained, and that there is a sufficient thickness of the composition over the rail base. After being rammed, the "floating" is ready for immediate use, and may be paved upon without delay, which is a decided advantage.

Incalculable damage is caused to new tracks through too long a length of track being exposed to the variations of temperature. This remark has been made previously, but it is necessary that the fact should be established. If a track is to be well laid, and the cost of maintenance reduced to the smallest possible amount, the effects of the expansion and contraction of the metal must never be lost sight of, and so in connection with the "floating," care must be taken that it is covered up as soon as possible. If wet floating is laid, then the length open must be reduced as much as possible, but it is strongly recommended that the "floating" should be pounded in moist as described, so

that the paving may be laid without delay. Care must also be taken that the floating does not precede the paving by more than one rail length, and as previously stated the packing should not precede the floating by more than one rail length. There is nothing to interfere with the concreting and platelaying, but, on the contrary, the rails are packed, floated, and paved in as soon as the concrete is ready. The length of the job is reduced, and speed of the construction is increased, and as one operation overlaps another, the effects of expansion and contraction are effectually reduced.

## CHAPTER VI.

### RAIL LAYING.

RAIL laying, as a rule, does not receive that attention to which it is entitled, very little consideration being given to the important mechanical functions performed by the rails. The niceties of rail laying are frequently sacrificed, in this country, to the perpetuation of faulty street levels. It is quite a distressing sight to witness the rolling and pitching of tramcars on tracks which appear to be in excellent condition. Apart from the question of defects in the rolling stock, such irregular motions are caused by the variations in the cross levels of the track. When the levels of the track are being established, great care should be taken to secure a uniform cross fall. Owing to the camber of the roads it is seldom possible to secure a level track; but every effort should be made to limit this cross fall, which should not be varied except at curves. Too much stress cannot be laid upon the question of the cross levels of the two rails, which has been in many places almost entirely neglected, if smooth running is desired. It is obvious that a car is bound to have an erratic path when the longitudinal and cross grades are continually altering. Many an otherwise good track has been completely spoiled through an endeavour to make the levels of the track conform to those of a badly-constructed roadway. Of course, the main object is said to be economy; but it is false economy to save a few hundred pounds per mile on the first cost, as much additional expenditure is incurred in the subsequent upkeep of the track and rolling stock.

Much is said about the tramway cars monopolising the thoroughfares, but it must be remembered that they are the recognised medium for the conveyance of the general public, and are thus entitled to every consideration. Besides this, the regular and uniform grading of public thoroughfares is becoming a necessity in these days of motor-driven, long wheel base vehicles. Grades and inclinations which have been deemed suitable for horse haulage do not meet the requirements of to-day. The question is one of general interest, and demands the closest attention.

There are numerous important operations connected with the laying of the rails, and it is here proposed to deal with these separately. They are all of equal importance, and require the constant attention of an experienced tracksman if a perfect running track is to be obtained.

First of all, all rails must be carefully and accurately straightened, it is seldom they are in such a condition that they may be laid in the track straight away. They have

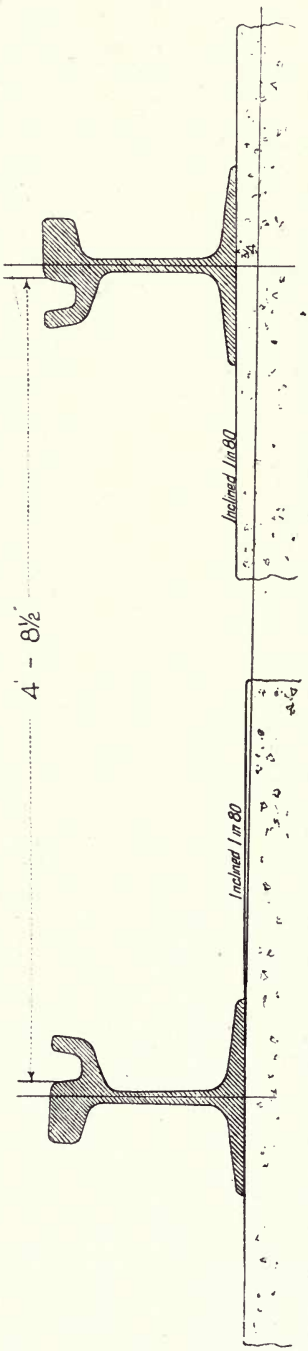



Fig. 24.—Rails in Correct Position with Bases in same Plane and Perpendiculars Parallel.—Inclined 1 in 80 from Horizontal to suit Camber of the Roadway.

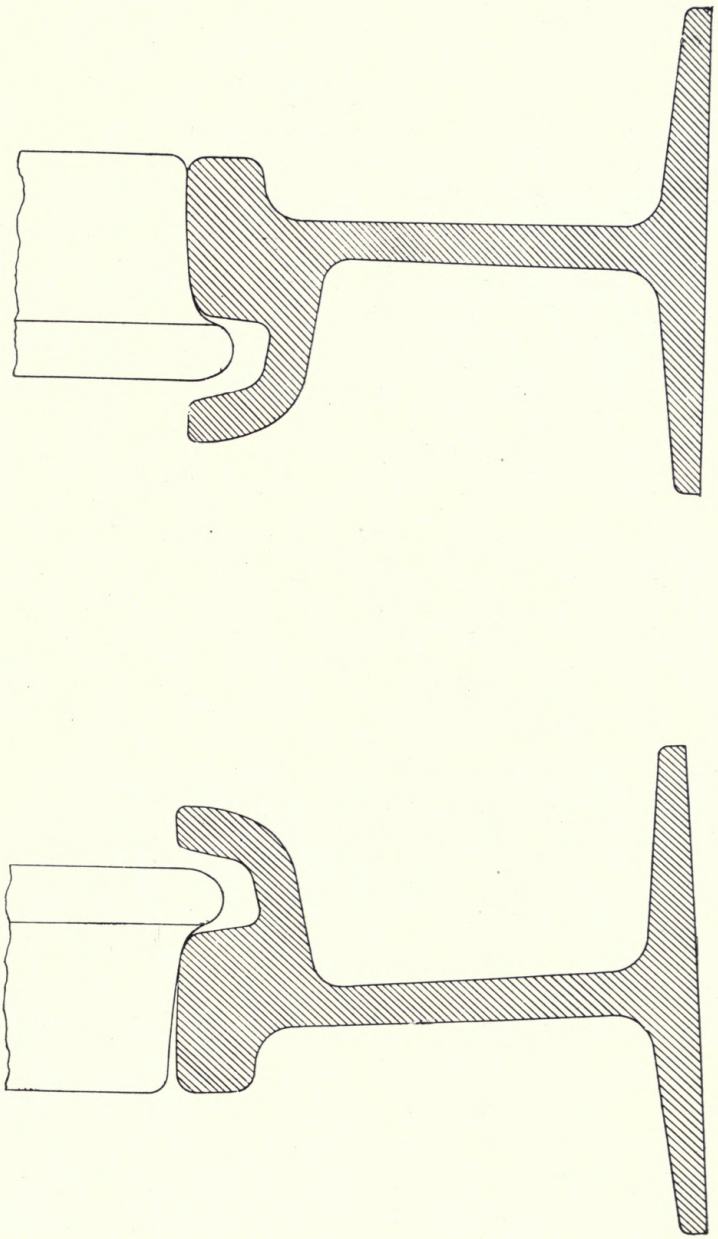


Fig. 25.—Wheel and Rail Contact when one Rail is Inclined from Vertical.

generally acquired a few "kinks" and curves in the loading, unloading, and handling. Unless these irregularities are very pronounced they may be removed after the rails have been coupled up and levelled in the track. In levelling and cross grading the rails, care must be taken to ensure that the rails are in the same "running plane." In other words their perpendiculars must be parallel and the bases at their same inclination. Figs. 24 and 25 show the correct and incorrect ways of

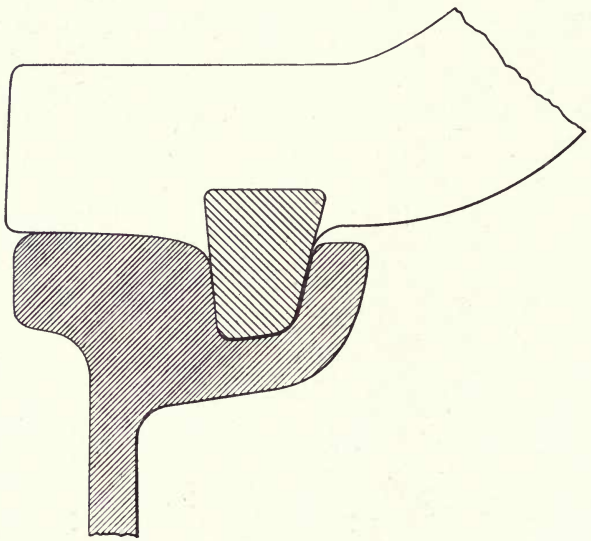


Fig. 26.—Rail Gauge showing both Track and Tread Gauge.

laying the rails. In Fig. 25 it will be observed that the wheels do not make a proper contact with the low rail, because it has a different angle of inclination to the high rail. Such cases are far from being uncommon; "canted" rails are one of the causes of irregular rail wear, and should be carefully avoided. For this reason all tie-bars should be fitted with threads at both ends and also with large disc washers, so that when the tie-bars are close together, say not more than 10 ft. apart, and the nuts are screwed up tight at each end, the

washers, being close to the web on each side, act as guides for the rail web and assist in maintaining the correct inclination until the rails are packed. In addition to this precaution the rails should be gauged with a gauge of the type shown in Fig. 26 and 27.

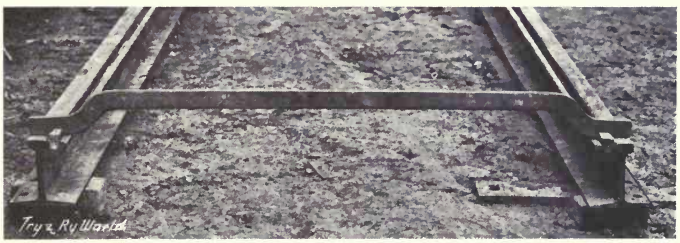


Fig. 27.—Rail Gauge showing both Track and Tread Gauge.

This gauge, besides determining the track gauge, is made to fit the two rail treads, and will at once reveal whether they are both in the same "running plane" or not. Fig. 28 shows a typical case in the road where the rail is either over canted or has a twisted tread which gives the same result. It will be noticed that the whole

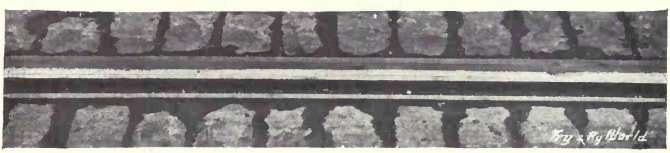


Fig. 28.—Imperfect Contact due to either the "Canting" of the Rails or to a Twisted Tread.

of the wear takes place on a very small area on the rail.

The same precautions must be taken in regard to the longitudinal levels or gradients of the tracks. Wherever possible, undulations should be removed even at the expense of relaying part of the sides of the roadway at such places. It is such short and changing gradients as these which give to the tramway car the familiar

"rocking horse" motion, which is very objectionable when the car is moving swiftly. Such alterations of the road levels will be to the advantage of the general vehicular traffic, which nowadays progresses more rapidly than formerly.

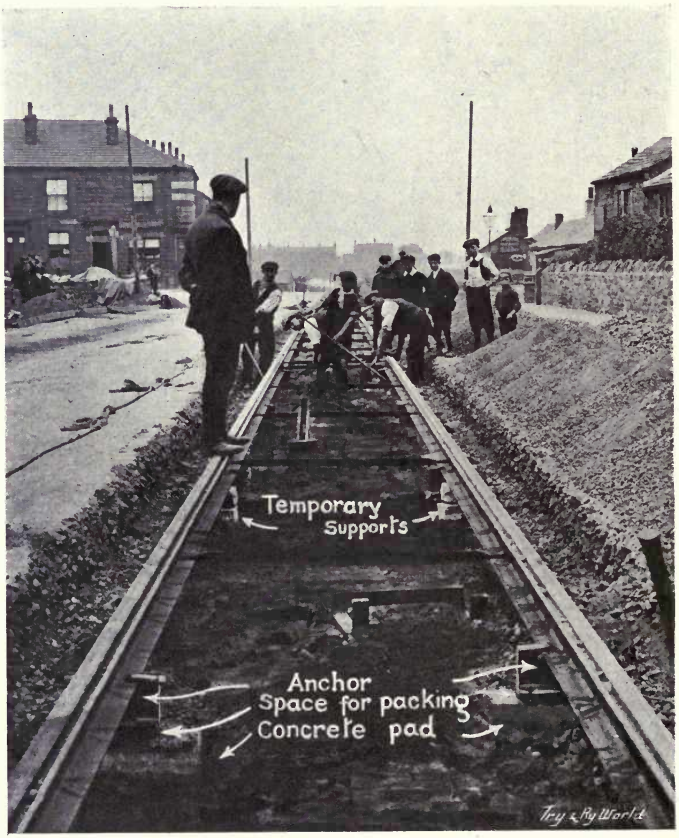



Fig. 29.—Rails Raised on Temporary Supports, Anchors attached, and the Concrete Pads.

In laying the rails it is recommended, where the track is to be anchored, that they should be laid upon temporary supports to their true levels. The anchors, which should be of a girder type, should then be attached to the rails and concrete pads 2 ft. by 1 ft. by 4 in. thick

should be laid beneath the anchors, and 1 in. below the anchor flange, as shown in Fig. 29. When these concrete pads are sufficiently hard the intervening space between the anchor flange and the concrete pad must be packed with cement and chippings. The temporary supports may then be withdrawn, and the rails will rest upon the anchors, which will determine the permanent levels. With anchors of a suitable girder type, and at intervals

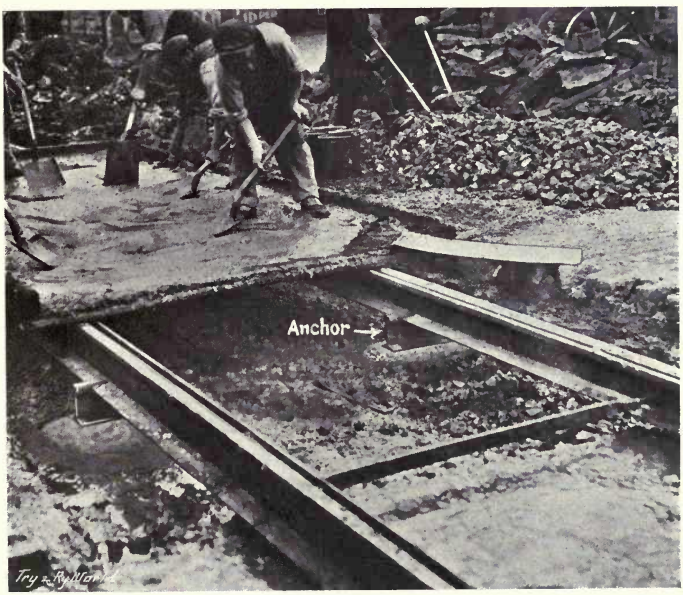



Fig. 30.—Cement and Chippings packed beneath Anchor.

of not more than 15 ft., there will be no chance of the levels being disturbed, and the concrete stages may be laid upon the rails, which is a decided advantage especially when working in narrow streets, without causing a permanent set in the rails. Fig. 29 shows the rails raised on temporary supports, together with the anchors attached and the concrete pads beneath them. Fig. 30 shows the rail resting upon the anchors and the concrete stage in position.

Every precaution must be taken to ensure the correct surfacing and levelling of the track. Each pair of rails must be carefully examined and the levels checked. In levelling and surfacing of the track it is advisable to set up the levels over as long a length as possible in order

Fig. 31.—Surfacing Rails in Front of Concrete Stage.

to secure long uniform gradients. The inspector should lay his cheek to the rail and sight along it, as shown in Fig. 31 ; a true bone will then be readily established, and any undulations and irregularities may at once be rectified. The rails must also be re-examined before they are concreted in as they are liable to alter their

position somewhat during the ordinary changes of temperature. For this reason it is recommended that anchors with a wedge or clip attachment should be used in preference to bolts, so that the wedges may be fitted loosely, thus permitting a certain amount of rail creep to take place without disturbing the anchors. The wedges may be driven "home" just before the rails are packed.

Unless such precautions are taken, the rails, in expanding and contracting, will draw the anchors through the soft concrete, causing local fractures which may ultimately develop and cause trouble subsequently. During hot weather a special examination should be made before the rails are packed to ascertain whether they have "hogged" between the anchors. There is a tendency for this to happen, and precautions such as the one mentioned above in regard to wedges should be taken, and no rails should be packed or paved which have these objectionable surface undulations. The wedges may be loosened for some distance and the rails got back to their true bone and alignment.

In laying rails the length of exposed surfaced track should be kept as short as possible. The expansion and contraction of the rails during the construction is the greatest difficulty which is encountered daily, and unless every attention is given to it it is impossible to secure a stable and smooth running track. It is an indisputable fact that much of the track maintenance caused by loose rails and paving is traceable to the expansion and contraction of the rails during construction. This question will be dealt with at length in another chapter.

So far only the levels of the rails themselves have been considered, and it is now necessary to deal with the tradesman whose work consists of laying the rails, and who is distinguished by the old-fashioned name, "platelayer." Platelaying is very little understood by

engineers in general, who are often entirely in the hands of their foreman platelayer, and the quality of the workmanship will depend entirely on the man's ability. The actual manipulation of the rails requires special skill, and care should be taken to obtain the services of a reliable, conscientious platelayer. Platelaying is a trade, and an exceedingly skilled one, and singularly enough it is perhaps the only skilled trade connected with engineering work which has no representative union to look after its interests. Only a long training can produce a thoroughly competent foreman platelayer. A foreman platelayer must possess an accurate "eye"; he must be able to line his rails as accurately as a surveyor can range a line; he must be able to bend a rail so as to produce a faultless curve; he must be skilled in the use of the tape, rule, and spirit level, and he must also have some considerable knowledge of smiths' work, drilling and fitting, etc. Platelaying consists of laying the rails and gauging and surfacing the same; the procedure is as follows:—

The rails are laid in the bed in pairs, the tie bars being loosely attached to approximate gauge. Not less than three lengths of rails should be coupled up at one time. They are next raised upon temporary supports to the correct levels, and set to gauge. It will probably be found that there are slight kinks and irregularities in the rails themselves, and these should be taken out by means of a straightening crow similar to the one shown in Fig. 32. This type of crow is fitted with loose pallets, which will engage either side of the rail head as shown. The anchors are next attached loosely to the rails, and the concrete pads previously described are laid beneath the anchor flanges, and when these are set sufficiently hard to take the weight of the rails, the space between the anchor flanges and the concrete is packed with cement and chippings. If the rails are to be curved, they should be "crowed" before being set to the final

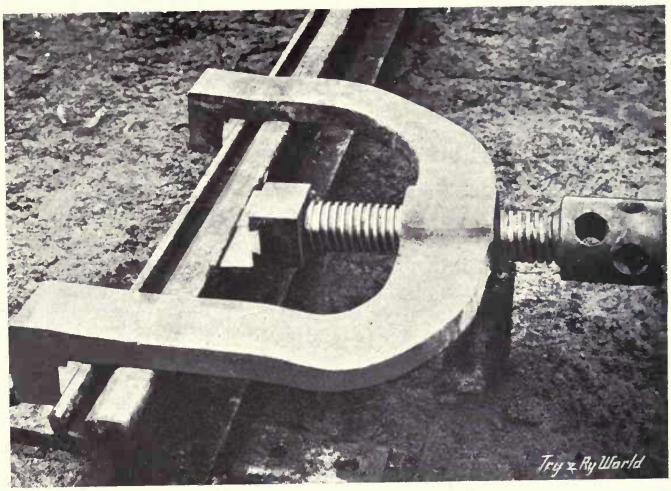



Fig. 32.—Straightening Crow with loose Pallets fitting either Side of the Rail-head.

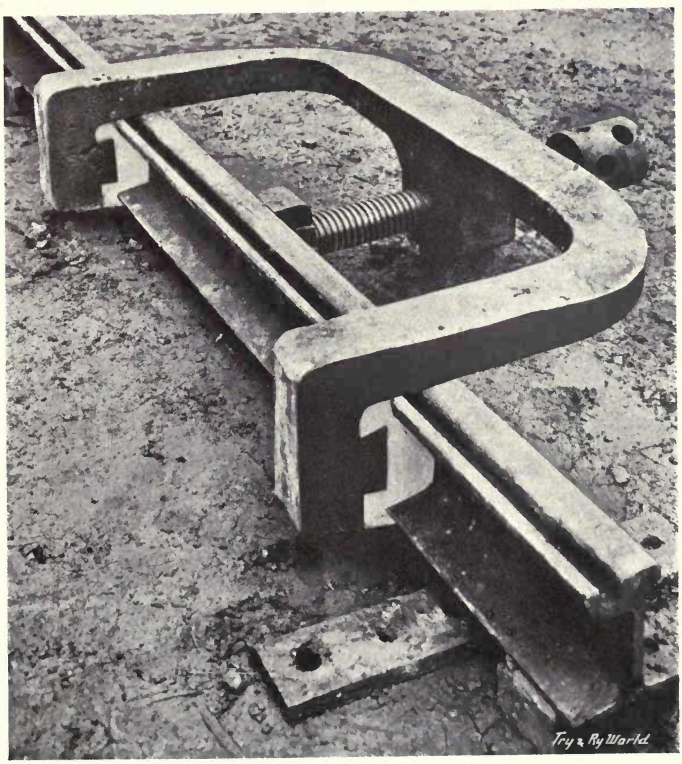



Fig. 33.—Rail Bender fitted with interchangeable Pallets which engage the entire Rail Section on either Side.

levels. A crow or rail bender of the type shown in Fig. 33 should be used. This rail bender is fitted with interchangeable pallets which engage the entire rail section, as shown in the illustration, and may be used on either side of the rail. Insufficient attention is paid to this important necessity. It is common practice for either a straightening crow, or at the best a profile bender which only fits one side of the rail accurately, to be used.

The use of such crows should not be permitted for the following reasons:—

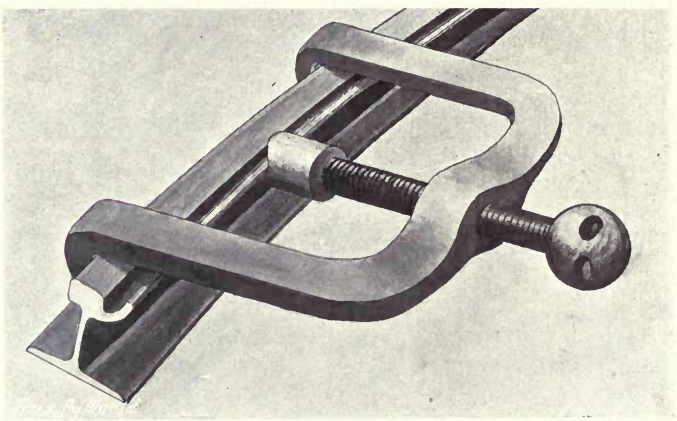


Fig. 34.—Rail twisted through improper Use of "Top" or Straightening Crow.

The two sides of a tramway rail differ to such an extent that it is impossible to get an ordinary rail-bender to engage all parts of the rail, which is a *sine qua non* in first-class work. The bender used for curving a rail must engage the sides of the head, web, and flange from either side as shown in Fig. 33, and this only can be done satisfactorily by means of interchangeable pallets.

Secondly, the use of ill-fitting rail benders causes a distortion of the rail head. The claws and the screw-boss are unable to engage equally either side of the rail, with the result that when the screw is tightened up either the

crow or the rail tilts, as shown in Fig. 34, and the pressure applied is not at right angles to the rail web, with the result that there is a decided tendency to raise or depress the rail tread, as also shown in Fig. 34, which is a most undesirable condition.

The curving of rails is accomplishod gradually in the following manner: A rail is "marked off" into lengths equal to the half span between the arms of the crow, and the crow is applied to the end of the rail as shown in Fig. 35, and the screw is tightened up so as to cause

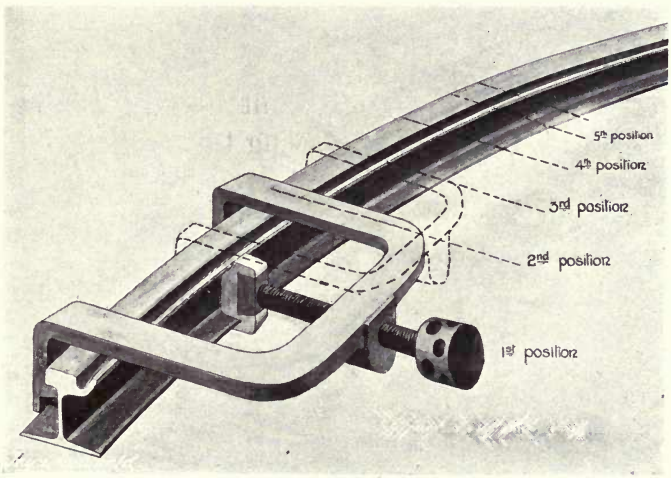



Fig. 35.—Method of curving a Rail.

the rail to bend. It is not attempted to obtain the required curvature at one application of the crow at each place; such a proceeding would unduly strain the rail and cause the formation of a series of "kinks" throughout the rail length. The curvature is acquired gradually by traversing the rail several times and applying a little more pressure each time until the desired radius is obtained. Rails vary in stiffness, and some do not readily acquire a permanent set, thus requiring more pressure and taking time to bend. Others respond too readily and are liable to "kinks."

On account of the variations in flexibility it is often necessary to alter the position of the crow. For instance, the crow may be advanced to a position half way between those shown in Fig. 35, so that the screw-boss and claws occupy entirely new positions on the rail. Too much care cannot be taken in the curving of rails, and all work should be done to template, with the exception of the large radius sinuous curves which are so common to tramway systems. The use of templates is advocated in addition to the setting out of the curves. By the use of these radius boards or templates, irregularities in curving, which are the cause of uneven curve wear, may at once be detected.

In Fig. 34 is shown the result of bending a rail by means of a surface crow. Owing to there having been no pressure upon the web and flange of the rail it has buckled. Profile rail benders are indispensable if permanent curves are desired, and care must be taken to enforce their use, for platelayers have a rooted objection to them, and prefer to use the light surfacing crows on the head and flange of the rail.

A rail imperfectly curved, as that shown in Fig. 34, cannot have a proper bearing on the foundation, and the web and flange, not having a permanent set, are liable to endeavour to return to their original shape, causing "kinks" and irregularities in the surface, and, finally, the tread being distorted, there is not a proper contact for the wheel treads, which is liable to be a source of danger in some instances and lead to derailment, particularly when the outer edge of the rail tread is raised, as shown in Fig. 36, causing the wheel to ride on its outer edge, and raising the flange out of the groove somewhat.

All rails must be bent to the required radius by means of profile rail benders, and on no account should it be permitted to "spring" the rails to the curve. Rails are very flexible, and it is possible to lever a track over

from the straight to a curved line without the use of benders. This is termed "springing," and is a very unsatisfactory and "jerry" proceeding. There being no permanent set in the rails, their potential energy is likely to cause the trouble previously mentioned. On sharper curves another common and faulty practice is to curve the outer rail of the track, and then "spring" in the inner rail to gauge with crowbars. The tie-bars are at once fitted, and they hold the rail in position until it is paved in. Where such practices were adopted it cannot

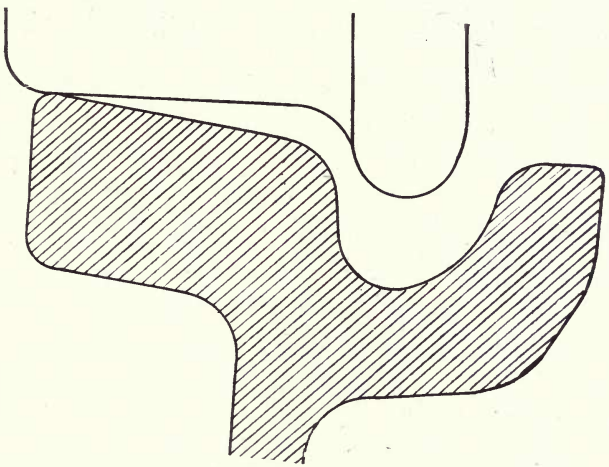


Fig. 36.—A Rail canted on sharp Curve through improper Bending and consequent Poor Wheel Contact.

cause surprise that trouble has been experienced in regard to loose rails, especially on sinuous systems. The platelaying cannot be too carefully watched, for there can be no doubt that too much has been left in many cases to the skill and conscientiousness of the platelayer.

### Anchors and Anchoring.

The question of anchoring is one upon which there is a considerable diversity of opinion. Many authorities hold the view that anchors are an unnecessary expense and their introduction has no good results. On the other hand, it is the experience of many others that the

introduction of anchors has accomplished the holding down of the track when other expedients have failed.

The writer's experience is that a properly anchored track is far more stable than an unanchored one, but that the result will entirely depend upon the care which is taken in applying the anchor. One often hears the remark that "We have tried anchors, but our track is no better for them." The only reply that the writer can make to these statements is that the anchoring was not efficiently executed. One view of anchoring is that it is a panacea for all track ills and that the introduction of a number of anchors at frequent intervals will cause the rails to lie down evenly and considerably reduce the expenditure upon maintenance. In the case of an existing track, great care is required in inserting anchors; if the rails are loose and "hog-backed," it is not to be expected that the forcible cramping down of deformed rails to their bed by means of anchors at intervals will procure easy running and freedom from repairs. The result of such a procedure is to form on the surface of the rail a number of smaller undulations in place of the one long arch which previously existed. In cases where the rails are so badly "hogged" it is necessary to strip the rails entirely from end to end so that the surface may be adjusted before applying the anchors; but the writer does not recommend the anchoring of rails in this condition, unless they are very far from being worn out, on account of the heavy expense of the attendant works. Anchors may be very effectively applied to tracks which are beginning to work loose but which are otherwise in good condition. In fact, if a few anchors are inserted at the affected places as soon as the defect becomes apparent, and the rails are carefully packed at the same time, an effectual remedy is obtained, provided, of course, that the foundations are whole. In all these cases it is necessary that repair works of this

description should be put in hand without delay and before greater damage is done. As a general rule, track repairs are not commenced until the track has become very defective, when remedial measures are costly and do not, perhaps, meet with the success which would have attended them at an earlier stage.

The anchoring of new tracks requires to be very carefully carried out, otherwise it may have an adverse effect upon the track. As in the other cases of track defects which have been referred to in these pages, all the trouble originates in the expansion and contraction of the rails before being paved in. Anchors are often attached to rails at frequent intervals, they are securely bolted or wedged on, and long lengths of track are exposed to the variations of temperature, with the result that the movement of the rails due to expansion and contraction draws the anchors through the soft concrete, causing local fractures which are sure to develop after the track has been in service some little time.

On the other hand, if the concrete has set sufficiently hard to resist this tendency and the rails have been packed, the anchors will maintain their position in the concrete and will retain their hold on the rails, with the result that the rails will rise off the packing between each anchor. The slight arch thus formed is seldom detected at the time and the rails are paved in in this condition, thus permanently establishing the deformation which imparts a see-saw motion to the cars, which is very objectionable and difficult to trace and cure.

Where the rails have been packed prior to this lifting of the rails between the anchors, the defect is often so slight that it is not discernible without careful sounding of the rail and a close examination of the surface with the eye to the rail. Consequently, the rail begins to work between the anchors, however close they are, and after a time water finds its way beneath the rail

flange with the usual results; and anchors are said to be useless for this purpose of holding the rail down.

In all operations connected with track construction or repair, due allowance should be made for the expansion and contraction of the rails, however slight the movement, and so, with anchoring, the anchors should not be too firmly attached to the rails until they are about to be paved in. They should be lightly fixed so that the rails may move in the direction of their length without disturbing the anchor or causing damage to the concrete. In order to allow free movement to the rails, it

Fig. 37.—Anchor attached by means of Wedges.

is recommended that all anchors should be attached by means of clips or wedges as shown in Figs. 37 and 38, so that they may be loosely fitted, allowing a certain amount of backward and forward movement to the rails, and afterwards, when the work is about to be paved in, the wedges may be driven "hard home."

The writer is of the opinion that the most satisfactory method of anchoring the joint is to attach two anchors, one on each rail, and not more than a foot from the rail end. The joint is thus doubly secured and a far better job is made than by the interposition of an anchor

immediately beneath the rail joint, which forms a kind of anvil upon which the rail ends are liable to be hammered, which is frequently the case on account of the impossibility of obtaining an even contact between two rolled steel surfaces, which will be referred to in the chapter on mechanical joints.

The writer has proved to his own satisfaction, time

Fig. 38.—Anchor attached by means of Wedges.

after time, that anchoring is beneficial to the track. In tracks subjected to high-speed traffic, anchors certainly defeat any tendency of the rails to work loose through excessive vibration set up by either the speed of the cars or on account of the "springy" subsoil; and it has been observed that anchored tracks give the best results where the vehicular traffic is heavy and continuous. Finally, anchors are of undoubted service in assisting to maintain the uniform gauge of the track.

# CHAPTER VII.

## JOINTS.

The mechanical joints used on tramways are all, more or less, variations of the well-known fish-plate joint.

The fish-plate joint has been abandoned in many instances as a total failure, whilst in others it is only tolerated on account of its low initial cost. At the same time, it must be pointed out that good serviceable fished joints may be obtained if only sufficient care is taken in making the joints, and reasonable attention is given to them afterwards. A joint is too often allowed to become almost beyond repair before it is attended to.

In all fish-plated tracks where the joints, as a whole, are said to have failed, there will be found several joints, at least, which have withstood the traffic without damage to themselves; indeed, in some of these instances the joint is scarcely discernible. Fig. 39 shows a view of such a joint which was in operation for 12 years and carried a service of one and a half million cars. From the fact that such fish-plate joints have been made to stand, it may safely be assumed that what has once been accomplished may be repeated. The general failure of the fish-plate type of joint is entirely due either to ignorance or neglect.

In making a fish-plate joint, both skill and patience are required; it is not a handy man's job, as is generally supposed. Given that the fish plates and rails are well designed, it is of the utmost importance that the minutiæ of the design should be adhered to; the rail ends should receive the closest inspection before they leave the works, and no rails should be approved unless

the ends are a true fit with the fish-plate templates. Each pair of plates should also be carefully gauged, and defective or inaccurate plates should not be accepted.

It is essential that the rails and fish plates should be obtained from the same works, so that they may be compared and tried on from time to time. Bad fish-plate joints are the inevitable result of the use of ill-fitting plates.

Rail and plate rolls wear considerably and at different rates, so that badly-fitting plates are likely to be the result of this wear unless the sections are compared and corrected from time to time. The rail ends should be true to section, and should be undercut about one-sixteenth of an inch so as to bring the two rail tables close together. In removing saw-fins from the rail ends at the works and in finishing off the rails,

Fig. 39.—An old Fish-plate Joint which had been in Service Twelve Years and carried a Service of 1,500,000 Cars without becoming battered, as shown by the Straight Edge.

care must be taken to ensure that the arises are left sharp; for sometimes there is a tendency for the men to bevel off the arises slightly, thus causing a decided gap when the rails are "butted up."

Such rails should not be used until they have been filed sharp again at the edge, for it is obvious that the gap thus caused will set up a "hammering" action. In preparing a fish-plate joint, all traces of black and red oxide scale must be removed from both the rail ends and plates by means of files, wire brushes, and scrapers. New fish plates, having been "dipped," have occasionally some coagulated oil about the bearing sur-

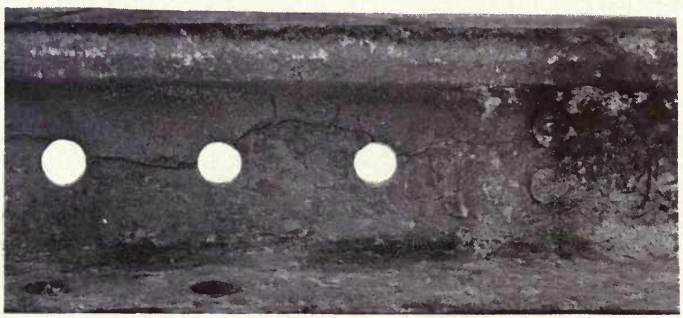


Fig. 40.—Split Web due to sledging home a tightly-fitting Fish Plate.

faces, which either prevents a good fit from being made or conveys a false impression of tightness; this should be removed, of course.

The fish plates should be "tried on" and removed, and the bearing surfaces of both the rail and the plates should be ascertained. It will be found that a file, in the hands of a man skilled in its use, will improve the fitting of the joints a hundredfold.

Neither loose nor tightly-fitting plates should be used; the former cannot be made tight without the use of liners, which is not only bad practice, but it cannot produce good results. Tightly-fitting plates should be either ground down or laid aside; the common practice

of driving a tight plate home with a heavy sledge hammer cannot be too strongly condemned, causing as it does a deformation of the section, and it is liable to split the web of the rail, as shown in Fig. 40. After the plates have been carefully fitted, they should be bolted up tightly by a skilled man using a short spanner, care being taken not to overscrew the nut; and after the track has been levelled and gauged the bolts must be again tried, and any slackness caused by the handling should be taken up.

The bolt heads, the plates, and the rail ends should be struck with a light sledge and the nuts should be tried again. No pressure should be applied to the wrench beyond a good strong jerk, otherwise the bolt is liable to become twisted or unthreaded. If the joint is left exposed to the changes of temperature for any length of time, it should be attended to and tightened up from time to time until it is paved in.

After the plates have been fitted and bolted up, the rail treads should be closely examined, and all inaccuracies of fit and section should be carefully removed by means of a double-handled file. A well-designed fish plate should be convex in shape, and should have a good flat bearing place for both the bolt heads and the nuts. Fig. 41 shows a section through a fish-plate joint where, for comparison, a convex plate and a flat plate have been used. It will be observed that, whilst the convex plate has withstood the tightening up of the bolt, the flat plate has buckled. Care should be taken to obtain good, well-made fish bolts; the cheapest article is not the best, and poor bolts contribute to the defects in a joint. The bolts should be well machined under the head, so as to bear uniformly on the plate. The same also applies to the nuts; they should be machined so as to make full contact with the other plate. Fig. 42 shows a defective bolt and nut and the

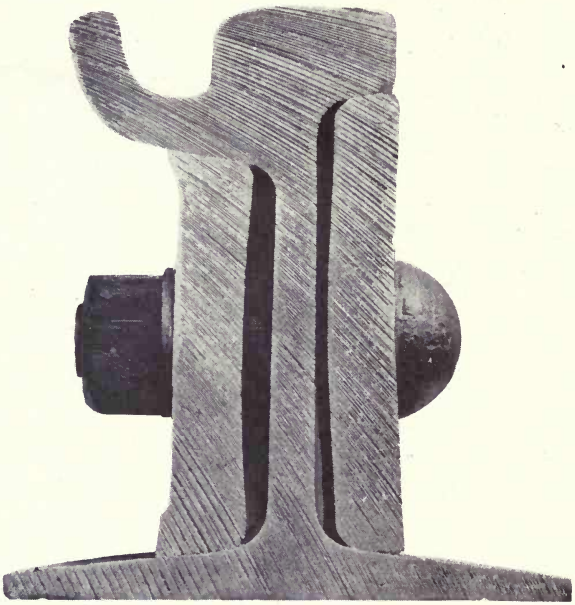


Fig. 41.— Showing Failure of flat Fish Plate.

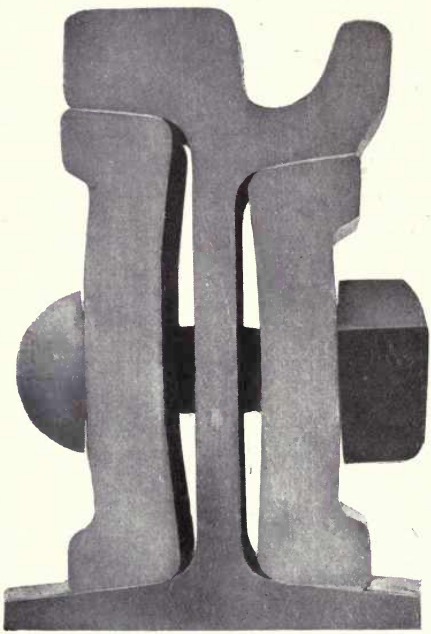


Fig. 42.— Showing bad Contact made by defective Bolt and Nut.

poor contact made, whilst Fig. 43 shows a well-turned bolt and nut and the excellent fit obtained. Lock nuts are an unnecessary expense on tramway tracks, for, owing to the paving, pitch, and cement grout, etc., it is not possible for the nuts to turn round.

Bolts may work loose, but lock nuts will not prevent this. The movement in a defective joint will work all the bolts loose without disturbing the nuts, by causing

Fig. 43.—Excellent Contact made by perfect-fitting Bolt and Nut.

them to extend. This has been clearly proved where lock plates have been used. On many of the earlier tracks long flat plates with six square holes for the fish bolt nuts were placed over the nuts after the joint had been made, as shown in Fig. 44. It was obviously impossible for the nuts to turn round, and yet the bolts worked loose. The looseness was found to be due to the elongation of the bolts. The bolts were not only extended, but were twisted, as shown in Fig. 45. Rail joints should not be allowed to work loose and become

battered. As a rule, the track and joints are neglected during the first few years in service, it being assumed that no attention is required, but it is during this time that all the damage is done to the rail joints, for it may be taken for granted that when attention is called to a joint by reason of its "hammering" or "springing" that the evil has existed for some considerable time. Joints should be frequently and regularly examined, and should not be allowed to "batter" themselves out of shape. It has been said that the "life of the joint determines the life of the rail," but this should be altered to read, "the neglect of the joint determines the life of the rail."

A joint should be attended to as

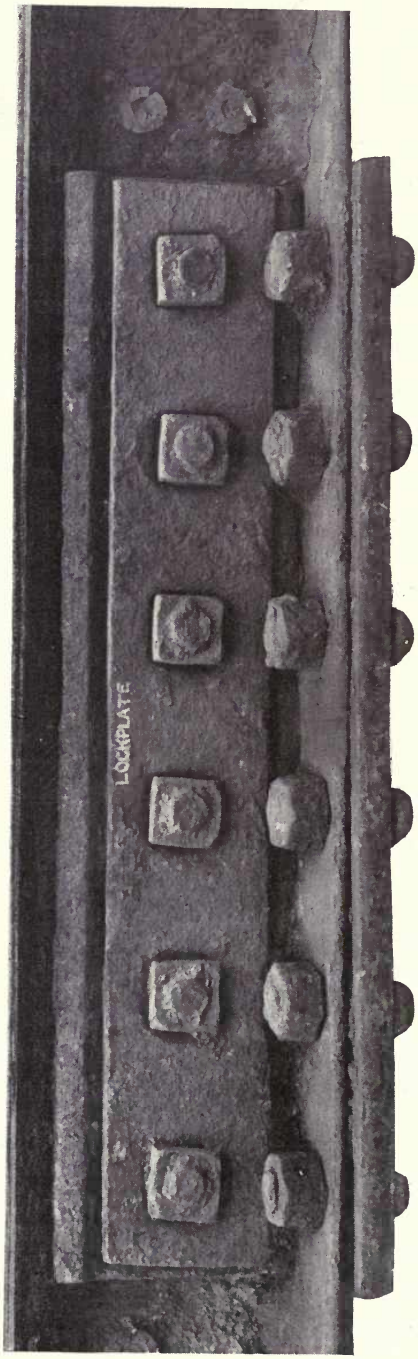



Fig. 44.—Fish-Plate Joint with Lock Plate. (It will be observed that it is impossible for the nuts to turn round.)

Fig. 45.—Showing worn and twisted Fish Bolts taken from the Joint shown in Fig. 53.

soon as there are any signs of looseness or of hammering; all traces of irregular wear should be carefully removed, the most suitable instrument for this purpose being a double-handed file similar to the one shown in Fig. 46. In using this tool care must be taken to preserve the profile of the partly worn tread, *i.e.*, the file should not be used in such a way as to produce a decided flat in the rail ends at the joint when the rail tables have worn convex, as is usually the case. Fig. 47 shows an instance of this, where, with the best of intentions, a flat has been filed on a rail tread. When a joint requires filing in this

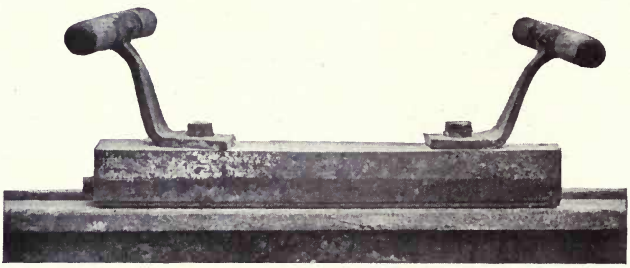


Fig. 46.—Double-handed File used for "dressing-up" Rail Joints.

manner, a small template of the tread should be prepared and tried on frequently during the filing. A joint should be opened out and examined the instant there are signs of looseness; the bolts must be tightened up, the rails packed, and all irregularities must be filed away. Joints should receive frequent and regular attention. With a little care and without much expense mechanical joints may be so made and maintained as to withstand the wear and tear of the track almost as well as the rail itself. In Leeds there are two tracks, one paved with soft wood and the other with granite, which have been in service for four years and have carried services of 1⅓ million cars and one million cars respectively. Both these tracks were relaid

Fig. 47.—Showing a Flat on the Rail Tread, at a Joint.
Caused by improper use of the rail file. Note the large area on the surface of the rail which is not in contact with the wheel tread.

Fig. 48.—Mechanical Joint, in wood-paved Track, which has carried a Service of 1,360,000 Cars in Four Years.

during the night time, the rails being in service the following day, and there is no more wear at the joint than at any other part of the rail. The joints are mechanical joints of the type known as "continuous rail joints;" they were carefully fitted, and the rail ends were filed true. During the first six months in service the joints were each examined weekly, all traces of irregular wear being removed. The joints are in splendid condition, and there has been no other maintenance charge on either track, neither of which is anchored. Fig. 48 shows a typical joint on one of these tracks. Ordinary fish plates, used alone, are not

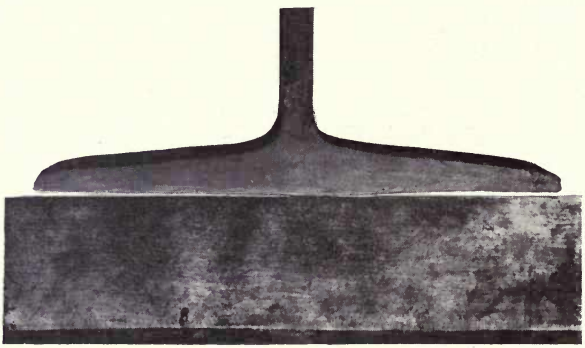


Fig. 49.—Showing Rail with "Rocking" Base.

recommended where the speed is approaching nine miles per hour; it is then necessary that some auxiliary jointing device should be used to engage the rail base. Sole plates or joint anchors have been used for this purpose, but there is, however, a very serious obstacle to overcome in perfecting the joint where such strengthening additions are made to the joint. The difficulty arises out of the irregularities in the rail bases, which prevent the formation of a proper contact between the rail and the sole plate or anchor. As a rule, the underside of the rail flange is very uneven, and at the best it only bears on the plate at a few points, and in some instances the rail has a rocking base, as

shown in Fig. 49. This is by no means an uncommon example, and it clearly demonstrates the difficulty of making a satisfactory joint. Fig. 50 shows a saw cut through a fish-plate and sole-plate joint, and a little study of this and the preceding illustration will help to solve the riddle, "Why do joints fail?" It is claimed by many joint specialists that their joint or anchor

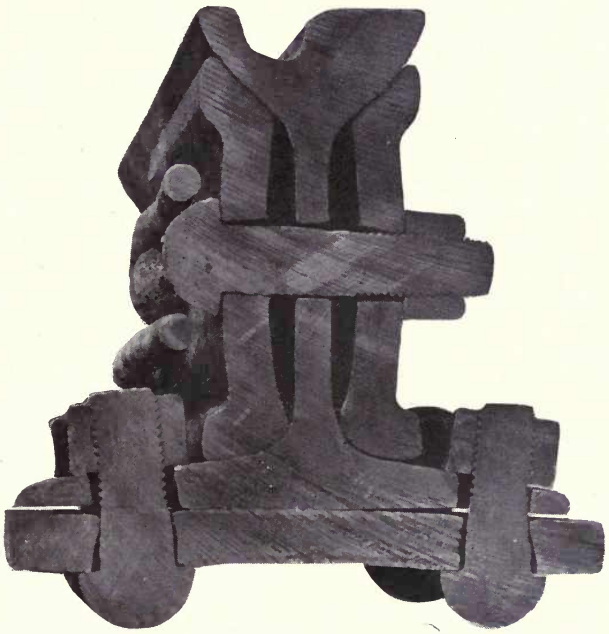


Fig. 50.—Showing Saw Cut through complete Fish-Plate and Sole-Plate Joint.

Note the imperfect contact between the rail base and the sole plate.

plates are a "pressed fit," *i.e.*, the device has been fitted hot to a section of the rail at the mill; but this does not in any way ensure a true fit. There cannot be a true pressed fit unless the joint plates are actually fitted to the identical rail ends they are to secure in the track. And even if it were possible to do this, it would lead to much confusion and a great amount of inconvenience; the joint plate would have to be attached to one of the

rail ends, and the other rail end would have to have a distinguishing mark, and it will be readily seen that such an arrangement would be too impracticable to execute. In order to overcome this difficulty, rails should be designed with thicker and narrower flanges, so as to neutralise as far as possible the effects of the contraction of the metal after rolling. Purchasers are entitled to, and should insist on being supplied with rails having reasonably true bases, and it is suggested that a considerable improvement could be made in

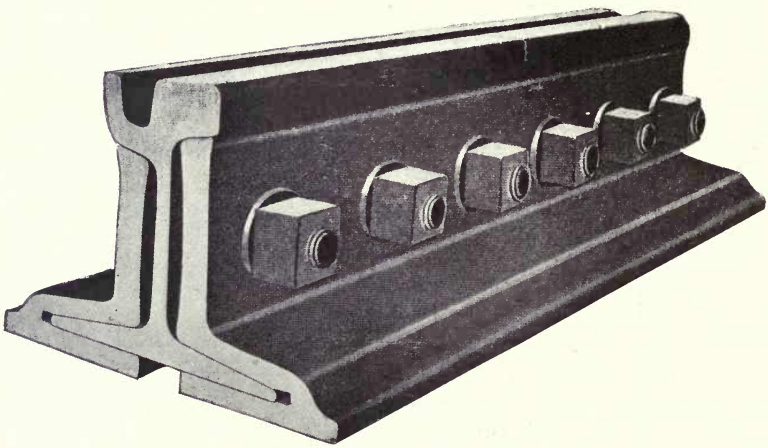


Fig. 51.—The Continuous Rail Joint.

this direction by the introduction of a roller into the mill which would engage the entire rail base during one of the finishing passes. Figs. 51 and 52 show mechanical joints which will give excellent results, if carefully fitted.

There are many theories in regard to the reaction which takes place at a mechanical joint between the wheels and the rail ends, but so far very little practical attention has been given to the matter. In the first place, the trouble is commenced by the presence of a gap at the joint between the two rails, the presence

of which, however slight, is sufficient to start the joint working if it has been at all carelessly fitted, and in any case its presence is sure to be felt sooner or later, hence the necessity of frequent inspections, and the careful filing of all joints showing the slightest indications of "hammering."

In up-to-date tracks the well-anchored and supported rails permit the wheels to travel to the extreme end of the rail without deflection, the trouble being caused by

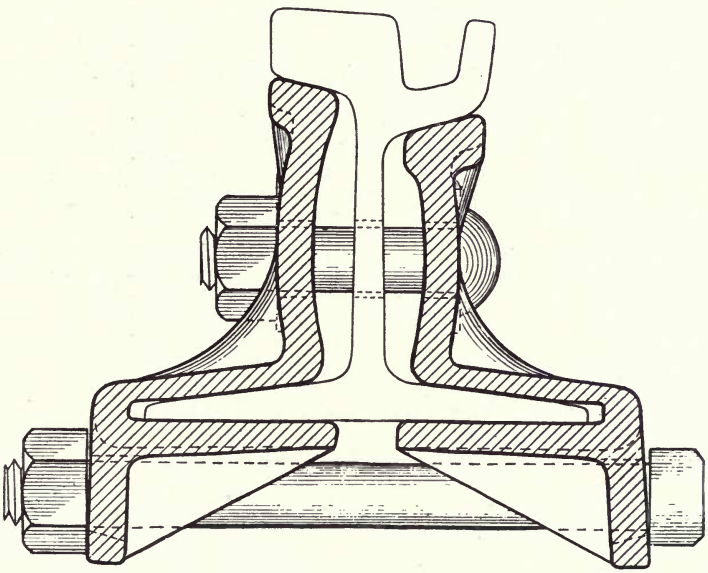


Fig. 52.—The Atlas Joint.

the slight drop of the wheel as it bridges the gap between the "running" rail and the "running on" rail. This drop is very slight to commence with, but it increases and causes a decided depression on the end of the "running on" rail, which is, of course, equal to the widening of the gap between the two rail ends. The wheels roll off the end of the "running" rail, and alight some distance from the end of the next rail, the distance varying in this country from 1 to about 6 in., according to the speed of the car. Fig. 53 shows a typical

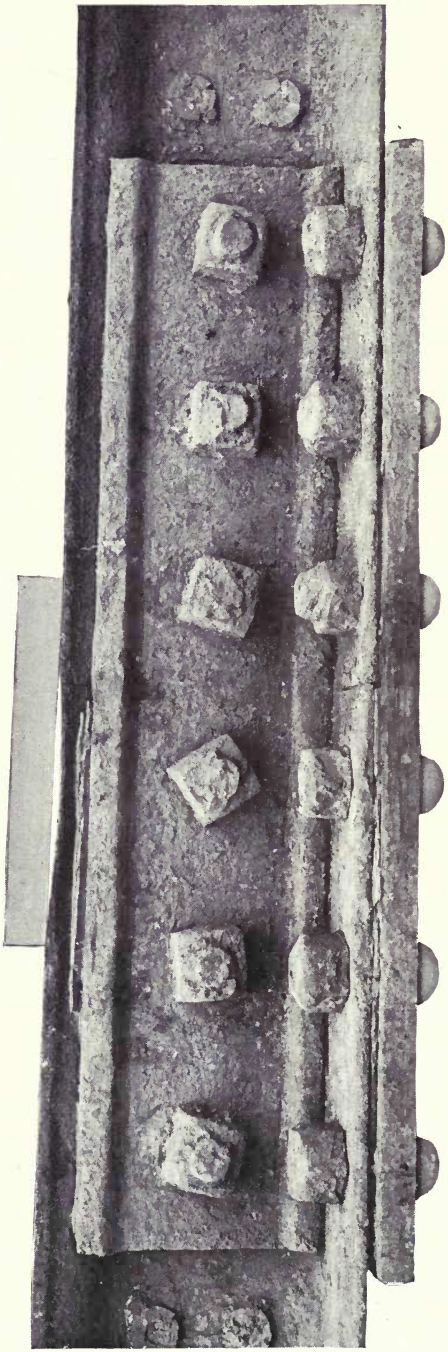


Fig. 53.—Badly-battered Mechanical Joint, as shown by the Straight Edge.

"dished" or "hammered" mechanical joint. It will be noticed that the "running" rail has scarcely received injury, whilst the "running on" rail has been battered hollow and has apparently been raised, judging from the presence of the liners between the rail head and the fish plate.

Other factors in the failure of the mechanical joint are the position of the rail web and the actual bearing of the car wheels on the rail tread. It is intended to deal with this matter more fully under the heading of Rail Design, but it may be observed, in passing, that as

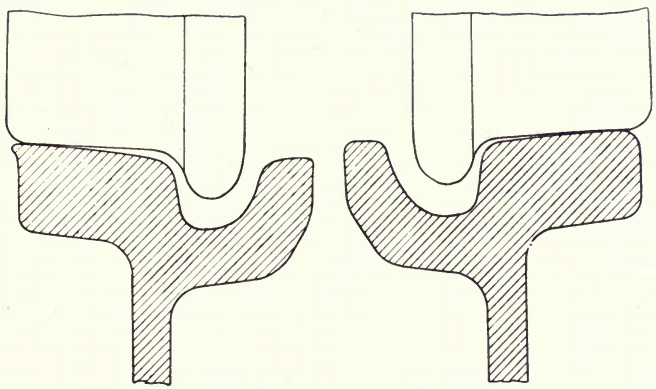


Fig. 54.—New Tyres on Old Rails.

tramway tracks are seldom laid level, there is quite an appreciable "cant" in the two rails, due to the camber of the road, as shown in Fig. 25, which, as the wheels pass over the joint, imparts a torsional movement to the "running on" rail end as it receives the blow from the car wheel. Again, owing to the web not being immediately beneath the tread of the rail, and as the bearing of new tyres on old or partly worn rails is, as shown in Fig. 54, on the outer edge of the treads only, it is obvious that as the load is non-axial, there is little to prevent the outer edge of the "running on" rail from becoming beaten down as shown in Fig. 53.

## CHAPTER VIII.

### JOINT WELDING.

NOTWITHSTANDING the good results which may be obtained from well made and well-tended mechanical joints, such joints are far from approaching the trackman's ideal. However carefully a joint may be made and maintained, at the best there is always a fine division between the two rail ends, which will certainly lead to trouble unless the greatest care is taken in preparing and maintaining a mechanical joint. The aim of all tramway engineers is the obliteration of the joint, and with new rails this may now be said to have become an established fact. There have been several attempts to weld tramway rails, but none of these processes have been so successful in the welding of new rails as the alumino-thermic process popularly known as Thermit welding, which is now in use on 60 different tramway undertakings in this country alone. In the earlier days of Thermit welding there were undoubtedly many instances of trouble due to the breaking of the welds; but on later works, where greater care has been exercised, in addition to the improved methods of welding due to wider experience, the percentage of broken welds has been reduced to an almost negligible quantity. One of the principal objections raised in regard to Thermit welding by those who experimented with the process in its earlier and less perfect stages was that the joint was liable to be honeycombed, although presenting an apparently sound exterior. That many of these earlier joints were in this way more or less defective cannot be denied, but such

defects were not in any way inherent in the process itself, but were, as is frequently the case, the result of inexperience.

In an article on "Blow-Holes in Thermit Welds: Their Cause and Prevention," Mr. G. E. Pellissier, dealing with the repairing of larger pieces, gives the following satisfactory explanation and solution: "In making Thermit welds it sometimes happens that upon machining it is found that the metal is not perfectly solid, and it is often assumed that this fact is peculiar to the Thermit process and cannot be avoided. This, however, is not the case. As welding with Thermit is essentially the same as making a steel casting, the same process of reasoning will apply to both cases, in so far as the conditions are the same. In making steel castings, the chief cause of blow-holes is the presence of ferrous oxide in the metal, and this is usually removed by the addition of some very active deoxidiser, such as aluminium, manganese, or silicon. Thermit itself is a mixture of iron oxide and aluminium, mixed in such proportions as to completely reduce the oxide. As sufficient pure manganese is added to the charge of Thermit to reduce all oxides which may be present in or on the parts to be welded, it is evident that the blow-holes which sometimes occur in Thermit welds cannot arise from this cause. What, then, is the cause? It is the writer's opinion that the explanation is to be found in the difference of temperature between the parts to be welded and the Thermit steel when poured. When a weld is made with Thermit in the ordinary manner, and the parts to be welded are not brought to a high temperature before pouring the Thermit steel, what actually occurs is this: a small volume of Thermit steel is brought into contact with a large amount of comparatively cold metal, which conducts away the heat of the former so rapidly at the

junction of the two metals that it soon becomes too thick to flow, and as the mass cools the decrease in volume, due to shrinkage, is not provided for by the metal in the riser. The result is shrinkage, or so-called blow-holes." In ordinary tramway practice it is obviously not possible to bring rails to red heat, but the presence of a few blow-holes in the weld does not in any way affect the strength of the joint.

The truth of this is borne out by the fact that, in a broken weld, the collar of Thermit steel is rarely if ever broken, the fracture being usually in the rail immediately outside the weld. Many broken welds in the earlier days of Thermit welding were due to the fact that the rail ends were not properly cleaned, and that rails were used which had been holed for fish-plate bolts, the presence of these holes causing a longitudinal fracture which spread from one hole to another. The head of the rail was thus suspended on either one side of the weld or the other for about a foot, and in deflecting under the traffic the rail treads, which were not in those days butt-welded as at present, pulled apart, and the destruction of the joint was complete. According to the practice employed at present, the metal is not brought up as high under the head of the rail as previously. In spite of this, more compound is now used, which goes to increase the width of the band. A larger quantity of slag is so produced, and this is utilised entirely to surround the head of the rail, thus bringing it to a welding temperature, and on the pressure being applied by means of the clamps, a thorough butt weld of the head of the rail is effected (Fig. 55). In Leeds alone 11,000 joints, representing a length of over 60 miles, have been welded on new and reconstructed tracks during the past eight years, and the total breakages during this period, which includes the earlier stages of welding, when the process and

its application were not so well understood, do not exceed 3 per cent., whilst observations taken on the tracks welded during the past four years show that the breakages are only about 0·5 per cent. In Manchester, as was stated by Mr. H. Mattinson at an annual Conference of the Municipal Tramways Association, five years' experience of Thermit welding has

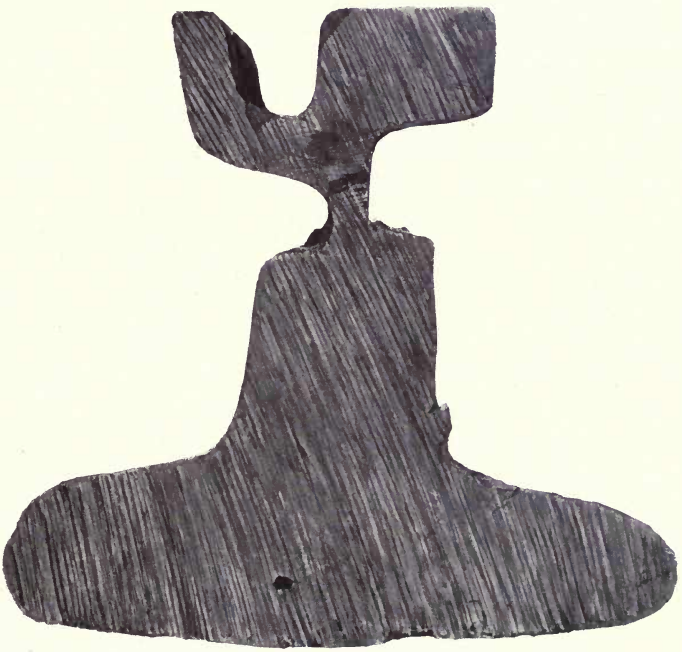


Fig. 55.—Section through a recent Thermit Weld, showing Freedom from Blow-holes.

resulted in less than 0·3 per cent. of breakages.* Whilst these results may be said to be quite satisfactory, and equally good results have been obtained on the majority of the other tracks that have been Thermit welded, still the alleged failure of the process on other systems requires an explanation. The making of a Thermit joint is an operation requiring the attention of

* *Vide The Tramway and Railway World*, October 12, 1911, p. 319.

a well-trained intelligent mechanic. Previously the Thermit Company sold the welding material and outfit so that the purchasers might do their own welding; now the company in nearly all cases supply trained men to do the work, and give a guarantee for a reasonable period. The failure, then, of some of the joints which were made by unskilled workmen may be said to be due to the total or partial neglect of the conditions required, and the failure of some joints made by the Thermit Company's own workmen has been proved to be due to the ill-treatment which the joints have received after welding and before being paved up.

One particular instance of this kind, which came before the writer's notice about eight years ago, will be sufficient to explain the ill-treatment referred to and to illustrate the ill effects. A firm of contractors undertook to construct a very considerable length of tramway track in a limited time, and, as is usual in such cases, everything was sacrificed to speed in construction. The rails were laid at what may be termed wholesale rates, several welding gangs being at work at the same time, each endeavouring to break existing records and to keep as close on the heels of the platelaying gangs as possible. The result of all this hurry was, as might readily be surmised, an abnormal number of broken joints. In the senseless rush which took place the rail ends were imperfectly cleaned and insufficiently preheated; in some cases the crucible was tapped before the completion of the reaction, and the clamps were removed long before the metal in the joint was set sufficiently to take the strain. In addition to this, the concrete, which was thrown in immediately the rails were welded, naturally took several days to set, and during all this time the temperature varied considerably, causing excessively long lengths of track to

expand and contract to such an extent as to get out of line and buckle in all directions. The effect of this was to cause numerous breakages before the work was paved in, whilst it was impossible to ascertain the number of joints which were damaged during this period and subsequently failed. If, therefore, welded joints are to be made a success, the effect of the expansion and contraction of the rails during construction must never be overlooked.

It is not intended to give a complete description of the process of Thermit welding in these Chapters—the subject being altogether too comprehensive—but to call attention to some of the more important requirements.* The following instructions on the operation of welding must be attended to in detail, if perfect joints are desired. First, the rails should have no bolt holes, but a small hole for a bond, where such is deemed necessary, is permissible where such hole is not nearer than 6 in. from the end of the rail. The ends of the rails should be undercut one-sixteenth of an inch in order to ensure a proper butt weld at the rail head when the clamps are drawn up. When setting the rails to be welded, it is necessary that precautions should be taken to ensure that the rails are in true alignment ; when the rail ends are set for welding, both should be perfectly true on the gauge line and at the tread. The rail ends should be raised to the extent of one-thirty-second of an inch for a length of 6 in. either way from the joint. Care must be taken to obtain true alignment between the joint and the rails on either side, otherwise much trouble will be experienced in securing a true line afterwards, coupled with the risk of fracturing the rails at the joint. Prior to placing the rails in their final position for welding, the end of each rail

* Full particulars may be obtained from the brochure published by the proprietors of the process, styled No. 2, June, 1913.

should be cleaned bright, and all foreign matter must be removed, not only from the end of the rail, but for a distance of 2 in. back on either side of the joint. The rail ends are prepared by means of a special ratchet file, which fits between the rail ends as held in the clamps

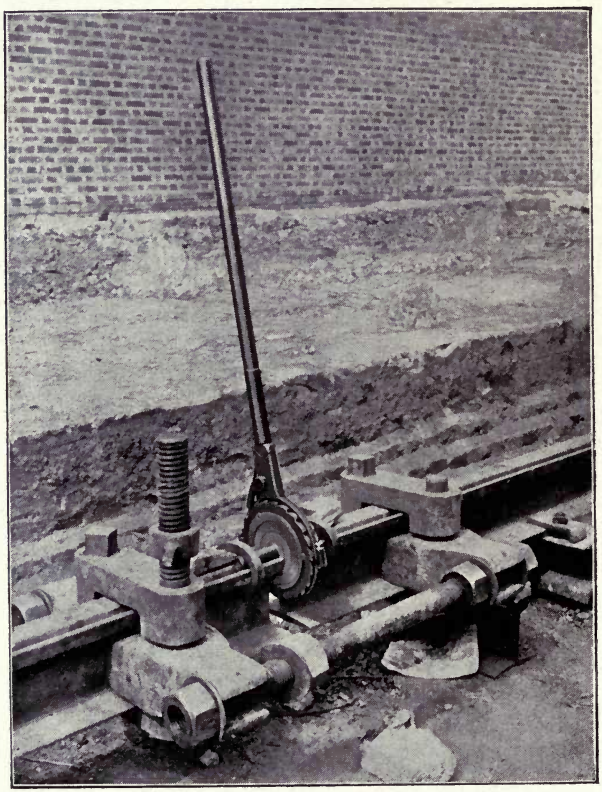


Fig. 56.—Patent Ratchet File.

(Fig. 56). In this way not only are the rail ends filed clean, but they are made absolutely square, so that when drawn together there is contact throughout the entire surface of the section, and a proper butt weld can be secured. After the rails have been placed in their final position, the flame from two powerful blow lamps should be directed upon the rail ends from either side (Fig. 57)

until they are a dull red heat. When this heat has been attained a hard steel wire brush should be briskly used all round the ends of the rails, particularly beneath the base where the rails cannot be examined. In luting the mould cases it is necessary that the greatest care should be taken to prevent the damp clay from being squeezed upwards into the inside of the mould case and thus coming into contact with the molten Thermit steel. Where the least particle of wet clay or damp matter of any description comes into contact

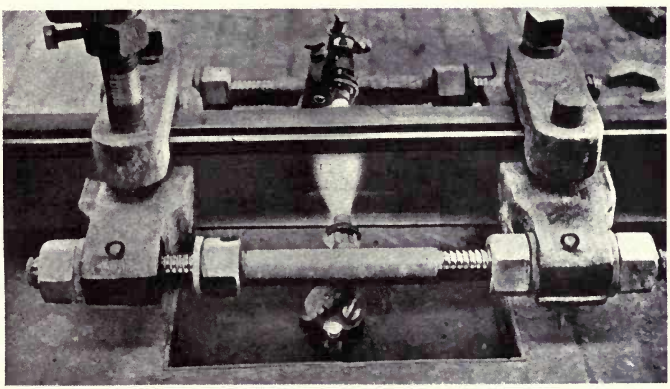


Fig. 57.—Operation of Pre-heating by means of Petrol after Rails and Clamps have been placed in position.

with the molten metal a slight explosion is caused, and a reaction of the molten metal is set up within the mould, causing the metal to boil up and sometimes to surge up over the head of the rail, thereby damaging it, and in any case causing a porous and defective weld in which the slag and steel are mixed. In attaching the moulds it is imperative that they should be placed exactly opposite the joint, and be pressed together evenly and tightly so that all parts of the moulds come close together at the top and bottom, and close to the rail web in the centre.

It is essential that the moulds should be perfectly dry, and that they should be heated with the blow lamps before they are attached to the joint. They should be made of a quartz sand of coarse grain, with just sufficient loam for binding purposes. The more porous the sand the better it is for welding purposes, so long as it binds firmly in the mould cases. The moulds should be pierced in a number of places with a fine pointed steel picker before being placed in the oven to dry. This serves two purposes; it ventilates the moulds and allows the moisture to escape during the drying process, and also provides an efficient means of escape for the gases generated during the running of the charge, which are otherwise liable to be retained in the weld, causing it to be porous or honeycombed.

In running the weld, great care must be taken that the crucible be exactly over the runner of the mould, and not more than 4 in. or 5 in. above it. It should be well balanced and perfectly secure in the holder. The length of time a crucible will last is variable; in Leeds as many as 40 runs have been obtained, but this is exceptional, 20 probably being nearer the average. In any case it is necessary for the small thimble forming the tap hole of the crucible to be renewed about every five runs. The welding compound should be well mixed by hand before being placed in the crucible, so as to ensure a uniform reaction throughout. The proper time to tap the crucible is when the reaction has entirely ceased and the steel has settled to the bottom of the crucible. In order to obtain a perfect butt weld it is necessary that the moulds should be left on for some time after the run has been made, so that the heat may penetrate through the head of the rail. From three to four minutes should elapse before the screws of the clamps are brought into play, and then they should be steadily tightened up one complete turn of the nut,

thus drawing the two rail ends well into one another. The slag covering the rail head should be allowed to remain as long as possible, in order to allow the rail to cool down gradually.

The welding clamps should be allowed to remain on as long as possible, and in any case they should not be removed for at least 15 minutes, in order to prevent injury to the weld from contraction during the cooling off. The rails should not be disturbed whilst the joints are cooling, and on no account should a rail bender be applied to the welded joint. On curved trackwork the rails should be "crowed" to the required radius before being welded. Every weld should be perfectly close jointed, the actual joint being obliterated, and there should be a smooth running surface. In order to ensure this, the rail head should be evenly hammered flat after the moulds have been removed, and should be smoothed off with a rail plane when cold.

The writer is strongly of the opinion that it would be possible to reduce further the number of broken welds if the rails were manufactured from a better quality of steel, and also if the section of the rail were to be redesigned; the present rail sections are only suitable for fish-plate joints, and it is quite time that the Standards Committee should direct their attention towards the production of a suitable welding section. It would appear that the web of the modern tramway rail is too thin to withstand the sudden application of the molten Thermit steel, and that it is liable to be damaged. It is suggested that the web could be thickened without increasing the weight of the rail, by reducing the metal in the flange, which is unnecessarily wide, and adding it to the web.

Recently a modification has been introduced for the welding of high carbon rails, and this process is also

generally adopted in the case of rails which, owing to their heavy section or chemical composition, are difficult to weld. The process consists in placing a mild steel

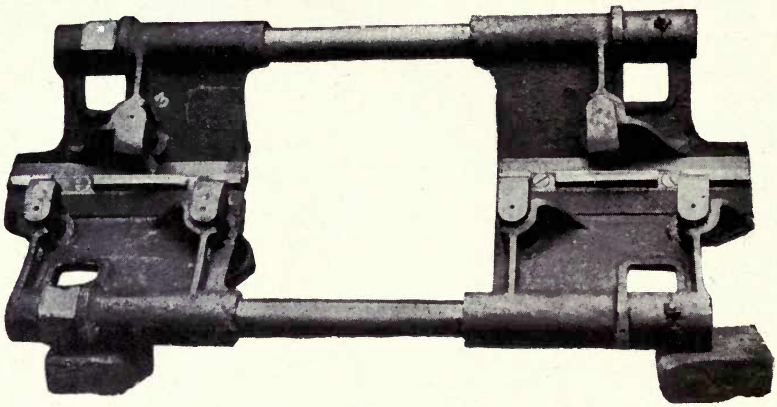


Fig. 58.—Underside of Rail Clamp for Welding High Carbon Rails.

shim, with a copper coating on either face, between the heads of the rails to be welded, and in order that the rails shall be kept in absolutely correct alignment, a

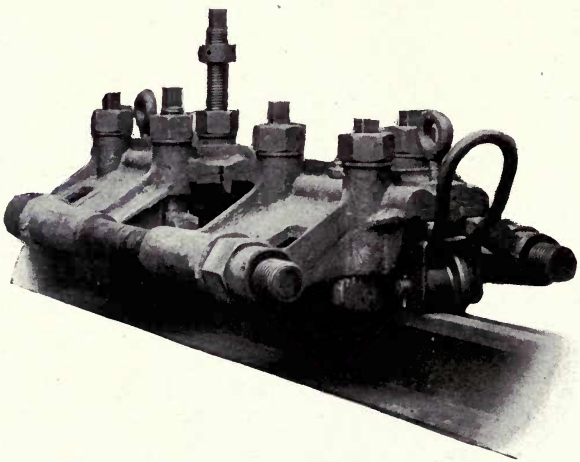


Fig. 59.—Rail Clamp on Carrier Running on the Rail.

special form of clamp shown in Fig. 58 has been designed. These clamps are fitted with guide pieces having a projection fitting into the groove of the rail,

and grip the head of the rail instead of the web, as in the older form. The welding is carried out in exactly the same way, but the rails need not be drawn up after welding, although, as a precaution, they are drawn up one-sixth of a turn; as a consequence, labour is saved in the subsequent filing of the joints. These clamps being made in one piece obviate dismantling and re-assembling for each joint. They are moved from joint to joint by means of carriers, consisting of two small wheels running on the rails (Fig. 59).

### The Tudor Electric Arc Welding Process.

More than 3,000 joints have been welded by the Tudor process at Liverpool, Glasgow, Halifax, Dundee, and Aberdeen, and these have proved satisfactory in every particular. The process in use is as follows: The rail ends are cleaned and the rails, bolted together between fish plates, are laid in the usual manner. The under-plates (a a a) are put in position, as shown in Fig. 60. A tent is placed over the joint to exclude the light from passers-by, and the joints are then welded. The fish plate and foot of the rail and the under-plate are securely welded together in three places on each side of the rail (six welds in all). Smaller welds (b b b) are next applied, when the ground is filled in and the joint completed by slightly filing the tread.

The repair joint (Fig. 61) is executed in the same way as the foregoing, with the exception that the ends of the defective joints are sawn off square, and a piece of rail, which may measure up to 14½ inches in length, is placed in position and bolted up with standard fish plates. It is immaterial whether the fish plates are old or new, as the weld holds all the parts securely together. If it is inconvenient to weld the joints as

soon as they are made, the ground may be filled in loosely about the joint and the remainder of the rail concreted up and filled in. The joints can then be re-opened and welded when convenient.

The operation of welding a joint (either Figs. 60 or 61) takes about one hour. Fishbolts may be

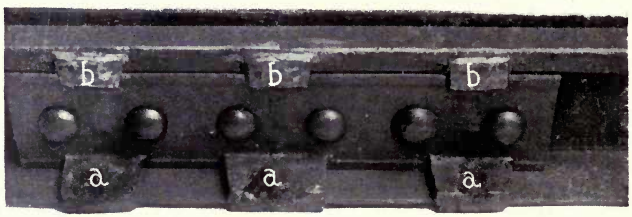



Fig. 60.—Simple Welded Tudor Fish Plate Joint.

dispensed with when the welding operations are completed. Bonds are unnecessary as the conductivity of the welded joint is nearly double that of the running rail.

Power is taken from the overhead trolley wire to work the motor generator of the welding equipment.

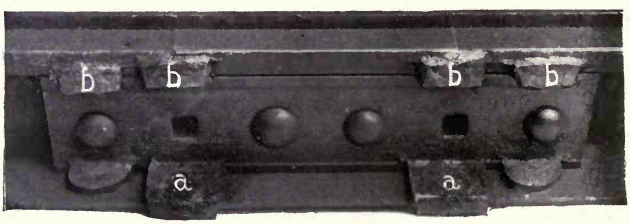



Fig. 61.—Repaired Joint welded.

The rails may be new or old, and of either high or low carbon content. The micro-structure of the steel is not injured or enlarged to a material extent by the heat applied.

## Expansion and Contraction.

It has been stated that "continuous rails cannot be permanently maintained in continuous contact with the

foundation," and that "the changes of temperature, though insufficient to strain the metals, may yet be sufficient, on roads not perfectly straight vertically and horizontally, to strain the pavement, and set up a movement in its parts." This theory is quite erroneous, and is disproved times without number on many of the larger systems, where many miles of welded track have been in operation for a considerable number of years, without any trouble being experienced in regard to loose rails and paving. It was conclusively proved by Mr. C. V. Boyes, F.R.S., in a contribution to *The Tramway and Railway World*, November 13, 1902, that the compressibility of steel rails and the weight of the paving and other materials, coupled with the adhesion between the rail and road bed, were sufficient to overcome any deleterious effects the changes of temperature might bring about owing to the surface of the rail being exposed. There is no denying the fact that some welded tracks have suffered to a large extent from loose rails and paving, and that such looseness is due to the effects of the expansion and contraction of the rails, but in all such cases the damage was done before the rails were paved in, and only the development was noticed afterwards. The expansion and contraction stresses in the rails require just as much attention on a tramway as they do on a railway, with this difference, that on a tramway the necessary precautions to counteract the effects have all to be taken before the work is paved in. The intelligent attention to the constantly changing temperature and the effect on the rails represents in many cases the only difference between a good track and the indifferent tracks which are so common. As has been stated previously, when long lengths of rail are exposed during hot weather, the rails creep forward during the heat and contract at night, and if such rails have been packed and brought

up to the final level, the creeping action does not tend to improve the packing, and it is not likely that the rails will return to exactly their original position at night. Then, as the rails are comparatively rough on the underside of the base, the top of the packing, being green or soft, is abraded, and, though minute, the spaces which then occur are sufficient to allow water to lodge between the rail base and the packing. The presence of water beneath the rail base, however small the quantity, is sufficient, under vibrations caused by heavy rolling loads, to set up the destructive hydraulic action known as "pumping." Again, and this with reference to broken welded joints, when rails are welded together in long lengths during hot weather, the rails being open are free to expand to their utmost. At night there is a certain amount of contraction and subsequent abrasion and slight arching of the rail, and expansion again during the following day until the rails are paved in. When a track has been constructed in this manner it is liable to both broken joints and loose rails, for this reason : As the track is paved during the daytime, when the temperature is the highest, the rails are beyond their normal length ; and although the compressibility of the steel, the weight of the paving, and the adhesion of the road bed are sufficient to prevent damage to the tracks, it must not be supposed that the difficulty ends here. As the rails gradually "cool off," and remain cool, on account of the non-conducting material surrounding them, contraction stresses are brought into action, and the whole of the rails are in a state of tension, like a piano wire, through the steel endeavouring to regain its normal length. In such cases the joints, however carefully welded, being still the weakest place in the whole, are subjected to incalculable stresses of an alternating nature, and are thus liable to failure from the effects of fatigue ; at the same

time the paving will be disturbed by the surging of the water beneath the rail flanges, caused by the vibrations of the rails during the passage of heavy electric cars at relatively high speeds. To avoid these bad results it is absolutely necessary that the paving should be kept as close upon the finished platelaying as possible, as has been previously stated, and even then every yard of rail should be carefully sounded before being paved in.

### Joint Repairs.

There are many ways of repairing worn or damaged mechanical joints, all equally effective if the work is skilfully carried out and taking for granted that

Figs. 62 and 63.—Joggle Plates.

the joints are not so badly worn or damaged as to be beyond repair. The most satisfactory procedure, however, is by constant attention to prevent the joints from becoming defective. Usually the joint is allowed to become battered out of shape before it receives attention. A regular inspection should be made of all the joints on a system by a conscientious person at frequent and regular intervals, and all defects should be attended to immediately. If such attention is bestowed upon a track during the first year after it has been put into service, the subsequent repairs will be of a trivial nature and the joints will wear well. In such cases the writer recommends that all bolts should be tightened up on the first indications of

looseness and all defective or badly-fitting plates should be replaced, the new plates being carefully fitted by a skilled workman. That is the course which the writer recommends for all new joints of this type; the making of a mechanical joint is a skilled fitter's job and should on no account be entrusted to labourers or platelayers, although the work should be done under the supervision of the foreman platelayer. Hammered joints may be raised by the use of joggle plates, such as those shown in Figs. 62 and 63, and the raised and damaged rail tread must afterwards be ground off to

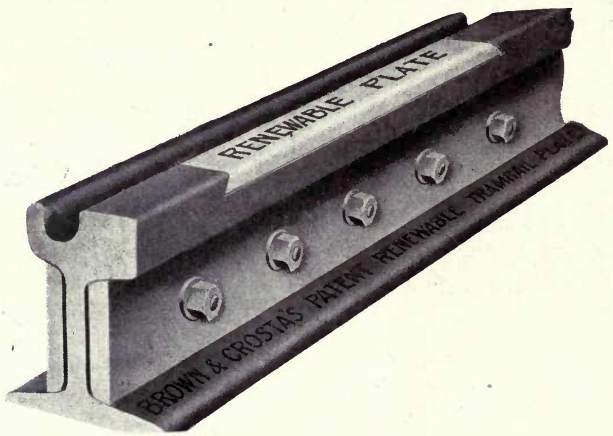



Fig. 64.—Renewable Joint Plates.

templet. If permanent joints are desired these plates must be a true "filed" fit with the undersides of the rail. It is a good practice to keep such plates in stock, with varying allowances for the wear which has to be levelled up. The plates selected for the purpose, when tried on, should be a tight fit so as to allow for the loss of metal in filing to fit.

The writer has had considerable experience with renewable joint plates of the type shown in Fig. 64, and the results are highly satisfactory. In order to obtain the best results from these joint plates it is

necessary that all loose track should be carefully packed, defective plates replaced and loose bolts tightened up simultaneously with the operation, otherwise the failure of the process is inevitable. The plates of this description, laid under the writer's supervision, were inserted part at night and the remainder during the day by operating a length of line as a single track; in the former case all incidental work was executed during the daytime. At night it was possible for the operator to insert three joints in four

Fig. 65.—Acetylene Generator in Use.

hours with one machine, whilst in the daytime five joints were fitted in nine hours.

Another means of repairing battered rail joints is by the oxy-acetylene welding process. In this form of repair the hollow joint has new metal applied to its surface by means of the welding blowpipe, the upset metal being afterwards carefully ground off to the exact shape of the rail tread. As in all cases of joint repairs it is necessary that all loose bolts should be tightened up and defective plates replaced. The cost of executing repairs of this description will depend entirely upon the condition of the joint and the amount of metal to be added. Joints have been repaired by this process for as little as 4*s*. 6*d*. per joint. The

following is a statement of the average cost of repairing a number of very badly worn joints by this process :—

| | Per Joint. | |
|---|---|---|
| | *s.* | *d.* |
| Taking up setts, packing, and tightening up joint and repaving | 5 | 0 |
| Welding, labour and materials | 13 | 6 |
| Grinding | 2 | 6 |
| Total cost, per joint, complete | 21 | 0 |

Fig. 65 shows a handy portable acetylene generator, several of which are in use on the Leeds tramways for welding, cutting and drilling. The oxy-acetylene and the oxy-hydrogen blow pipes are a very valuable addition to the list of time-saving track tools, and considerable advantage is derived from their use, one notable advantage being that it is possible to cut and drill manganese steel castings, hitherto an almost impossible feat.

# CHAPTER IX.

## RAIL WEAR.

The trite remark, "the life of the joint determines the life of the rail," is an empirical statement, the accuracy of which is not substantiated by a careful analysis of all the factors which conduce to the wear of tramway rails generally. It is true that the failure of the joints on many systems has necessitated the removal of the rails before the body of the rail has worn out; but there have been many instances where the greatest wear has taken place away from the joint, and where the joint has remained comparatively good. In one instance the writer is aware of the joints were perfect; but the irregular wear, the flowing, battering, and corrugation of the steel became so pronounced as to render the rails unfit for further service. The pertinent question, "What is the life of your rails?" is one of the most difficult of track problems, and it is not possible to answer it with any degree of accuracy on account of the numerous factors entering into the cause of rail wear, which appear to vary on each particular system. The wear of tramway rails depends chiefly upon the operating speed, the weight and design of the cars, the traffic density, the number and position of the stopping places, the frequent use of the brakes, the grades and curvature of the route, the vehicular traffic, the design of the rails and wheel tyres, the upkeep of the same, and, finally, upon the manufacture and composition of the rails. On account of the exigencies of the service and the local conditions, the design of the rails, their composition and manu-

facture, and the upkeep of the tyres are probably the only factors in rail wear that can be controlled. It is essential, therefore, that every consideration should be given to these questions, upon which depends such an important phase of tramway economics. It is not possible to compare the rate of wear on different tramway systems, or even on different routes on the same system, unless the general conditions are first of all proved to be identical. A few examples will serve to illustrate the truth of this statement. Taking the case of the operating speed, it may be conclusively proved that rails last longer on routes where there is a slow, frequent service, than where there is a less frequent service of cars run at higher speeds. An instance of this kind on the Leeds tramways showed that while forty million tons of car traffic were carried on a straight, level track, where the speed did not exceed eight miles per hour, not more than one-third of this weight was borne by the rails on a similar route, where the speed was about fifteen miles per hour. Figs. 66 and 67 are diagrams showing the rate of rail wear on two comparatively new tracks, both of which are straight and on the level, and are operated by similar cars.

The speed of the cars over the track shown in Fig. 66 is not more than nine miles per hour, on account of numerous cross streets. The rails have been in service for four years and have carried 320,000 cars, and, as may be noted on the diagram, the maximum thickness of the metal worn off the head of the rails is less than $\frac{1}{16}$ in. It will also be observed that the rate of wear is not uniform, and that the minimum thickness of metal worn from the rail head is about $\frac{1}{64}$ in. An examination of Fig. 67, which represents the rate of wear on the rails of a similar track, which have been in service for three years, and

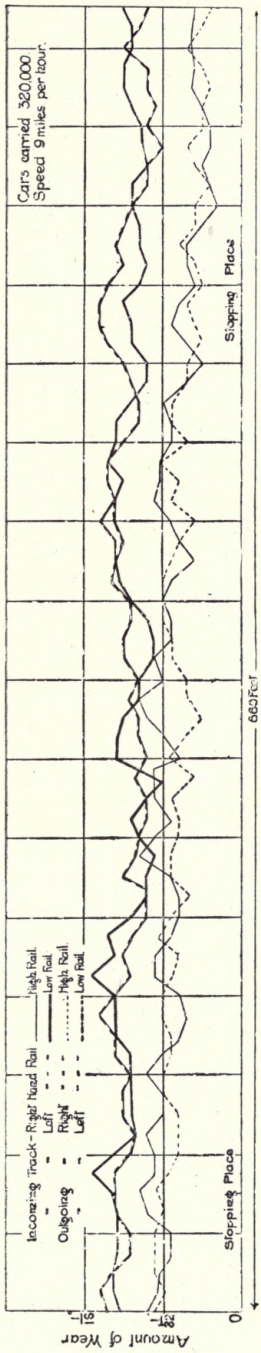



Fig. 66.—Showing Rate of Rail Wear on two comparatively new Tracks.

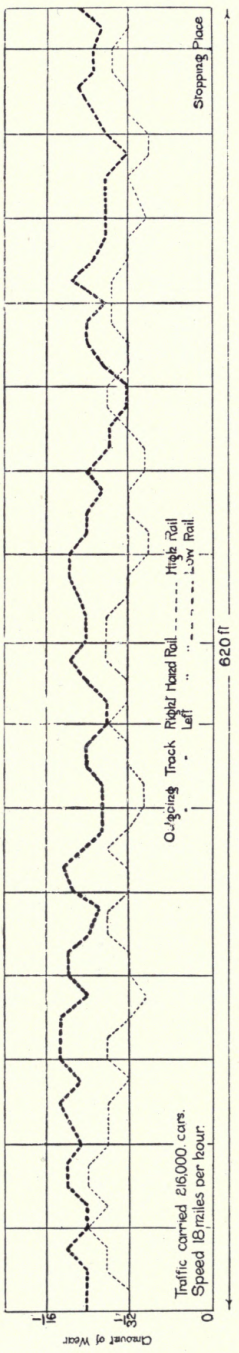



Fig. 67.—Showing Rate of Rail Wear on two comparatively new Tracks.

have carried a service of 216,000 cars, at a speed of eighteen miles an hour, shows about the same amount of wear as the preceding example, where over 100,000 more cars have been carried.

On these two diagrams it will be noticed that there is little or no increased wear at or near the stopping places, this being probably due to the fact that, being on the level, the cars as a rule will be brought to a standstill by shutting off the power and the amount of energy required to restart the car will be very small. Quite a different condition of affairs will be observed in Fig. 68, which illustrates a particularly good example of the wear which takes place on a steep gradient. This chart reveals that the wear on the rails on all parts of the gradient, both on the up track and on the down track, is exceedingly irregular, varying between $\frac{7}{32}$ in. and $\frac{1}{64}$ in., although the gradient is fairly uniform. As far as the writer can ascertain, the irregular wear can only be accounted for by the lack of uniformity in the quality of the steel. It will be seen that, apart from this uneven wear, the rate of wear appears to increase with the steepness of the gradient, and also that there is more wear at or near the compulsory stopping place than near the other stopping place which is not often used. A noticeable feature in the wear of tramway rails, which is revealed by careful gaugings, is that the wear on the low rail is consistently greater than the wear on the high rail. In other words, owing to the camber of the roadway, the outside rails on a double track are, as a rule, lower than the two inside rails and carry more weight, the wear being greater accordingly. The gaugings required for the preparation of the diagrams referred to were obtained by means of the handy little instrument shown in Fig. 69, which was invented by Mr. H. Mattinson, permanent way engineer, Manchester Corporation Tramways. Another

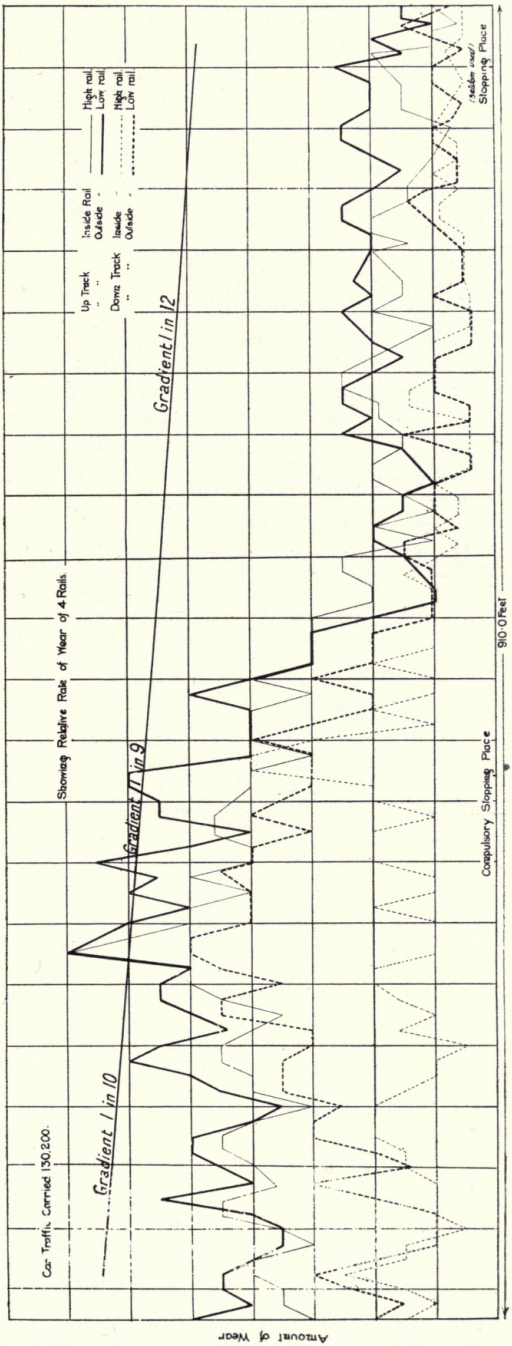



Fig. 68.—Example of Wear on steep Gradients.

curious feature of rail wear is revealed, by the application of the above described instrument, on a single track, with loops. As was described by the present writer in *The Tramway and Railway World* of November, 1910:—As a rule, the wear on the single track rails of a single line with loops is seldom greater, and is

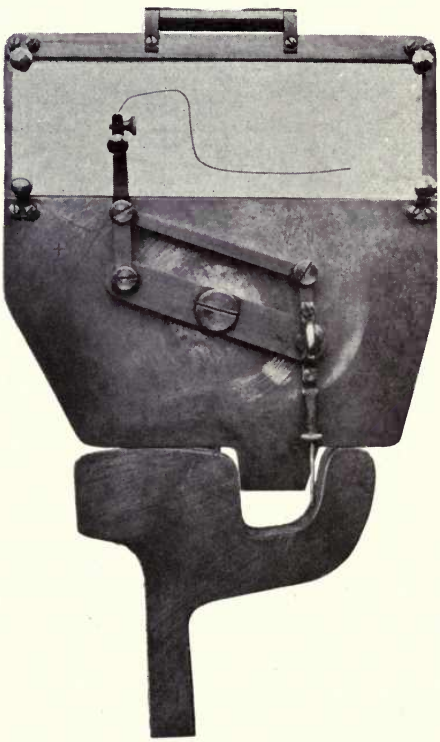


Fig. 69.—Instrument for gauging Wear of Rail.

frequently less, than the wear on the double track in the loops, notwithstanding the fact that the single track carries double the traffic and generally at higher speeds. Fig. 70 shows actual gaugings of the wear on the double and single track portions of various Leeds routes, together with the traffic carried. The suggested solution of the paradox is that the skin of the single track rail is not being continually drawn backward under the

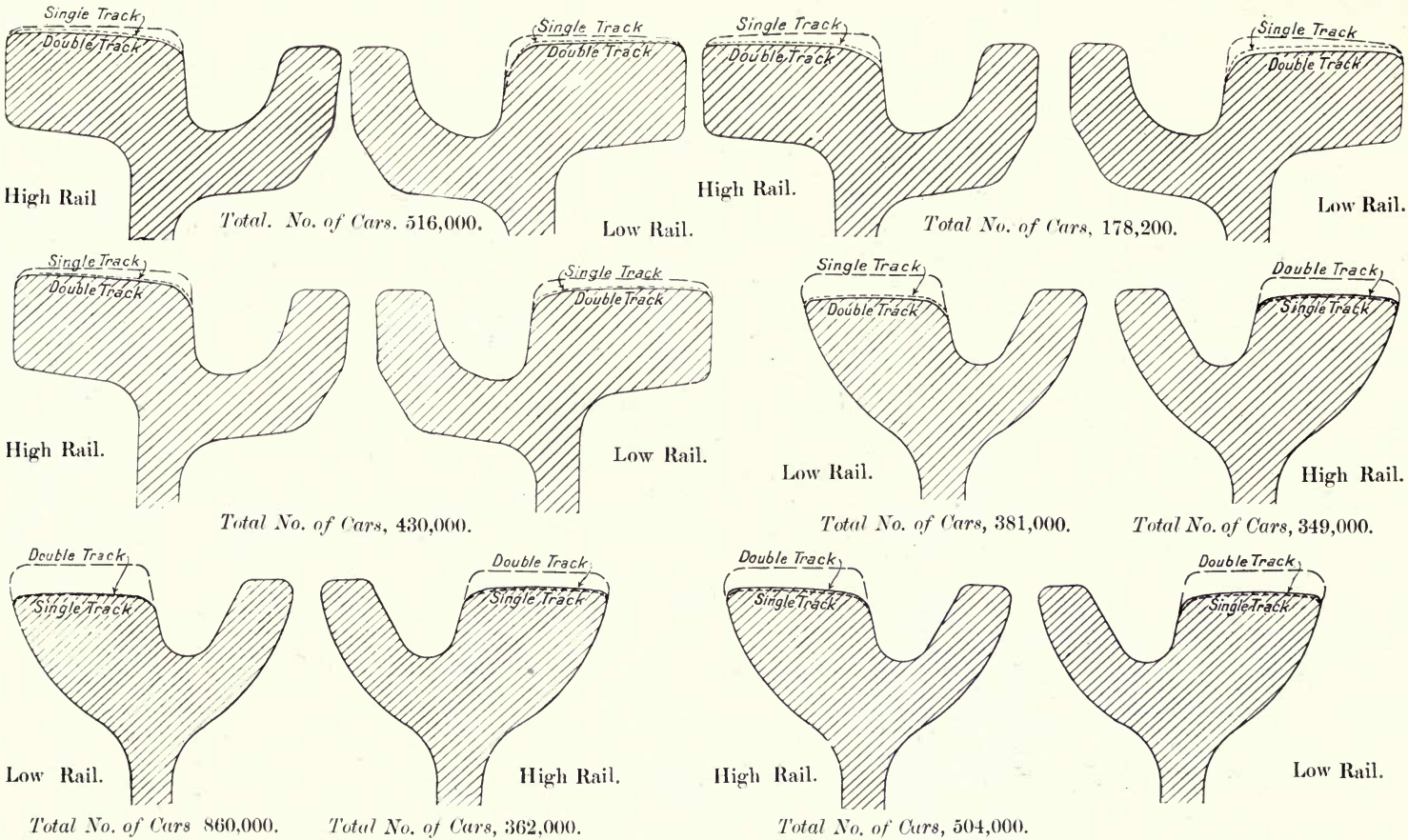



Fig. 70.—Comparison of Wear on Double and Single Track Rails.

cold rolling action of the wheels, but through the car traffic operating in both directions a neutralising action takes place and prevents the abrasion of the rail surface.

It is a fact that rails wear out much quicker where heavy ordinary vehicular traffic makes frequent use of the tramway tracks, as will be seen on referring to Figs. 16 and 17 in the chapter on Track Design, also in th e chapter on Paving. Fig. 71 also indicates very clearly the loss of metal in the rail head from this cause. The rail in this illustration was laid in a loop in the

Fig. 71.—Showing Loss of Metal in Rail Head due to Wear of Street Traffic.

track for over six years and had never been in service, all the wear being due to the vehicular traffic. There can be little doubt that the wear of the rails is influenced to some extent by the condition of the wheel tyres. In many instances the tyres are allowed to run too long before they are either turned up or replaced, the effect of badly worn tyres being to cause uneven bearing on the rails, which results in the deformation of the rail tread and loss of metal by extrusion. Figs. 72 and 73 show a number of worn wheel tyres.

*Rail Design.*—A considerable amount of unnecessary wear is caused by the faulty design of tramway rails.

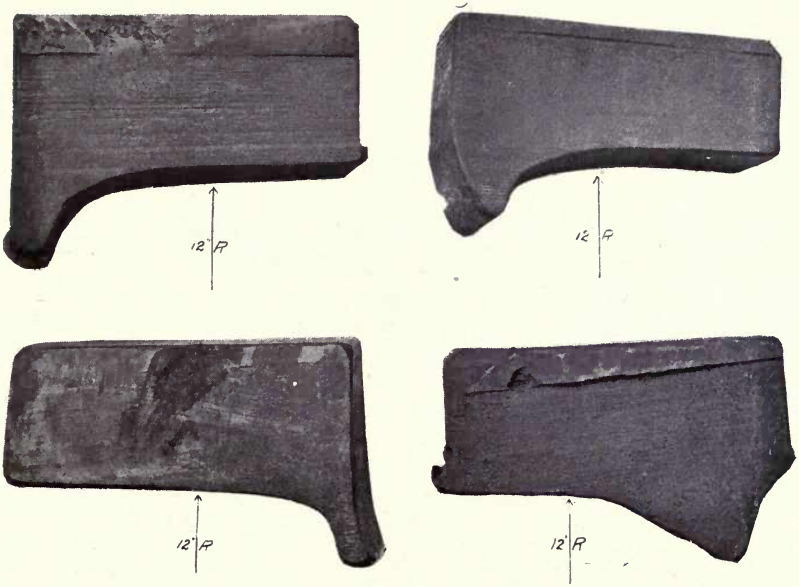



Fig. 72.—Examples of worn Wheel Tyres.

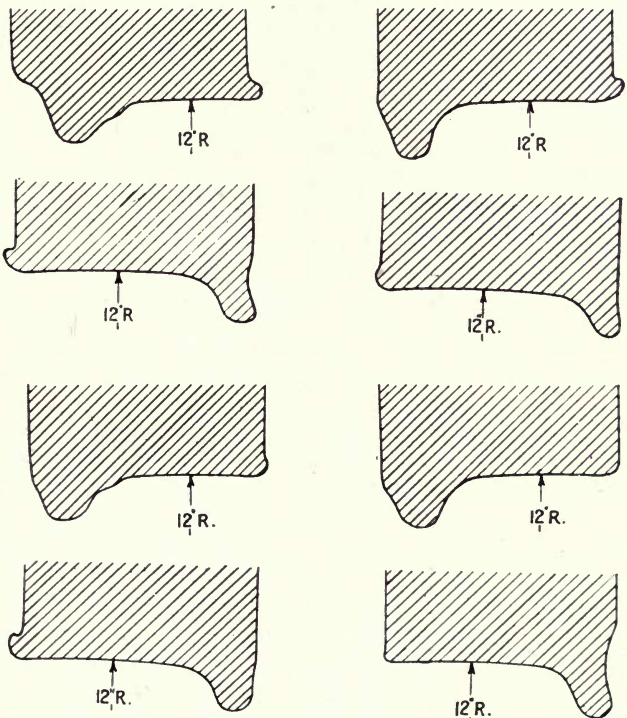
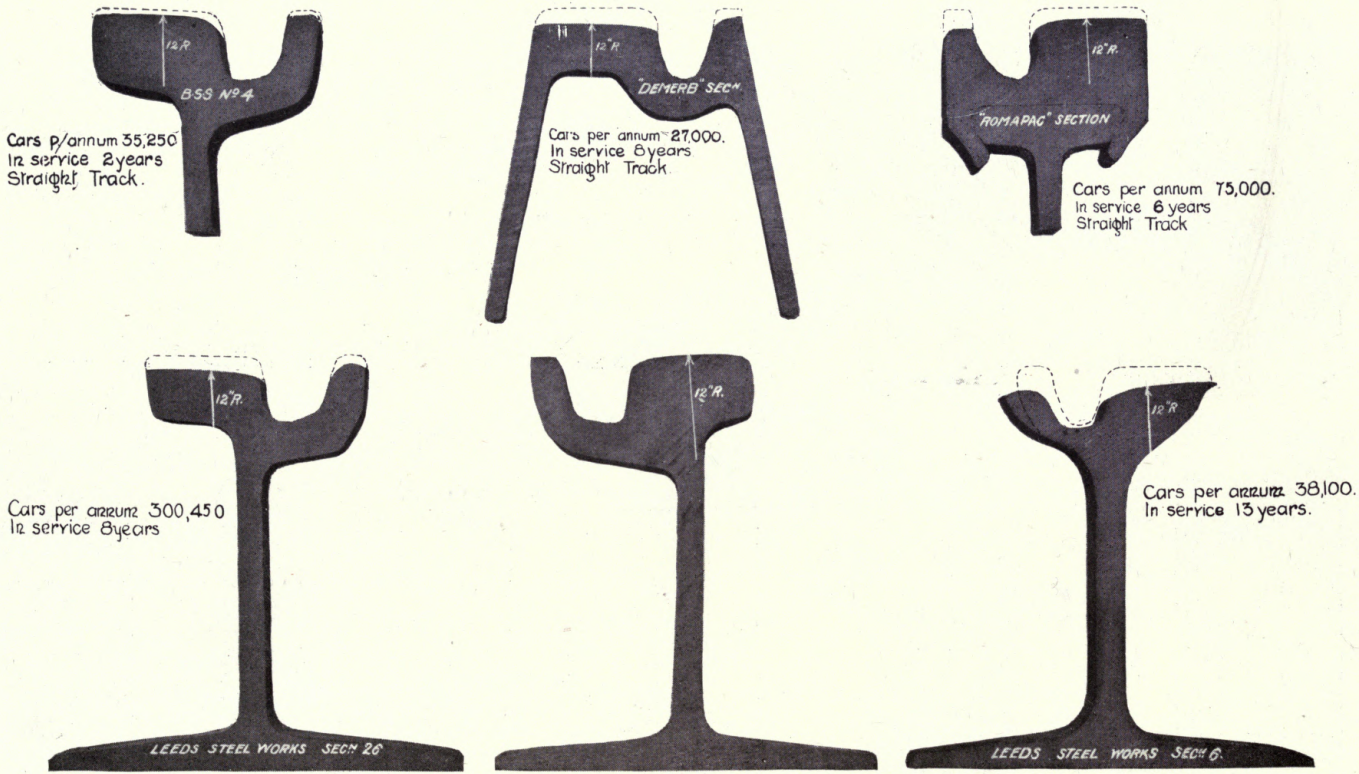



Fig. 73.—Examples of worn Wheel Tyres.




Special section of rail in use on Leeds City Tramways ("Holt" registered design). Unworn rail

Fig. 74.—Group of worn Rails of various Designs.

As the writer has previously pointed out (see *The Tramway and Railway World*, January, 1910), tramway rails, unlike railway rails, have either flat level treads or flat coned treads when new; but these treads ultimately become convex after a certain period in service, as shown in Fig. 74, which represents a group of worn rails of different designs taken from different systems. At the same time it must be noted that the wheel tyres wear concave (see Figs. 72 and 73). It is obvious that it is not possible for a partly worn wheel to

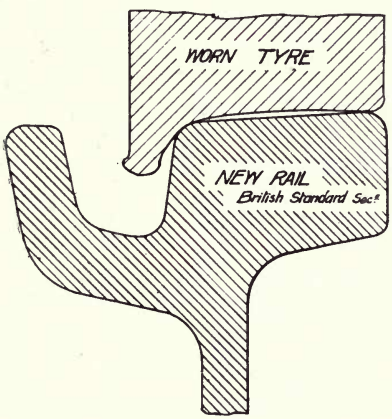



Fig. 75.—Faullty Contact between new Rail and worn Tyre.

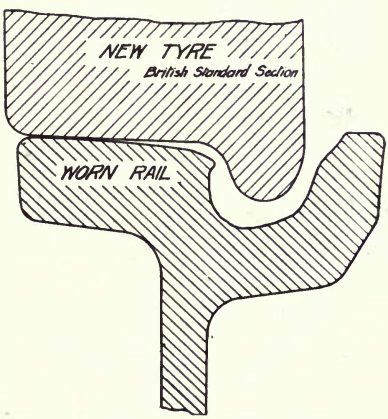



Fig. 76.—Faulty Contact between new Tyre and worn Rail.

make a perfect contact with a new flat-topped rail; this is clearly demonstrated in Fig. 75, and in like manner it is not to be expected that a new tyre will make a suitable contact with a partly worn rail; the contact will be as shown in Fig. 76. In the latter case, the wear on the wheel being local, it is worn to a fit with the rail in a very short time, but it takes some years under an ordinary service of cars to bring a flat-topped rail into proper contact with the wheels, and during this period much irregular wear takes place. The detrusion of the metal in the tread commences immediately the rails are put into service.

Fig. 77.—Showing Broad Wheel Contact after 48 Hours' Service on Leeds' Special Rail.

This is due to the unequal contact between the wheel and the rail treads, which concentrates immeasurable pressure on a limited area, thereby causing an unrestrained flow of metal. The writer has observed frequently where new rails have been laid that quite a substantial beading of extruded metal will form on the gauge line of the rails after about forty-eight hours in service. This beading is ultimately shorn off by the wheel flanges, but the same action continues until the rails have assumed a convexity of about 12 in. radius, as shown in Figs. 72 and 73.

In Leeds, rails have been used with flat level treads, with flat coned treads, and also with treads slightly rounded and sloping away from the groove, but the result is always the same, the treads become convex, and slope towards the groove at an angle of about 1 in 21. From this it is obvious that in order to obtain the best results the rail tread should be designed so as to resemble the partly worn tread, and where this is done the extrusion of the metal ceases, and the partly worn tyres immediately make a proper contact with the rails (see Figs. 77 and 78).

The irregular wear referred to takes place on new systems as well

as upon those which have been in operation for some time. The wheel contact in such cases is near the edge of the groove. This is indicative of the irregular wear that is taking place, and which continues until the rail tread is moulded under the car traffic to the shape required by the car wheels. With coned wheels and tyres it is obviously impossible to maintain a uniform contact with the rail when the wheels are in motion, seeing that the wheels are endeavouring to ride upon varying diameters at the

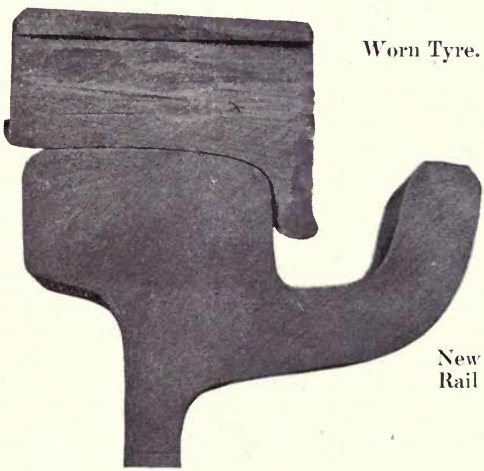



Fig. 78.—Good Contact between worn Tyre and new Rail.

same time. The result is that there is a constant tendency for that part of the wheel tread nearest to the flange to advance, and for the outer edge to lag, or else both movements to occur simultaneously, thus increasing the friction and abrading the rail, causing noisy running and loss of energy.

Fig. 80 shows the relative position of two wheels on the same axle when rounding a curve, or when out of position on the straight. It will be seen that the contact between wheels and rails is reduced to a minimum, and that the points of contact are at A

and B, the largest and smallest diameters of each wheel. As to the position of each wheel, this is as it should be—on a curve, but the same situation occurs in the straight. Owing to the camber of the roadway one rail

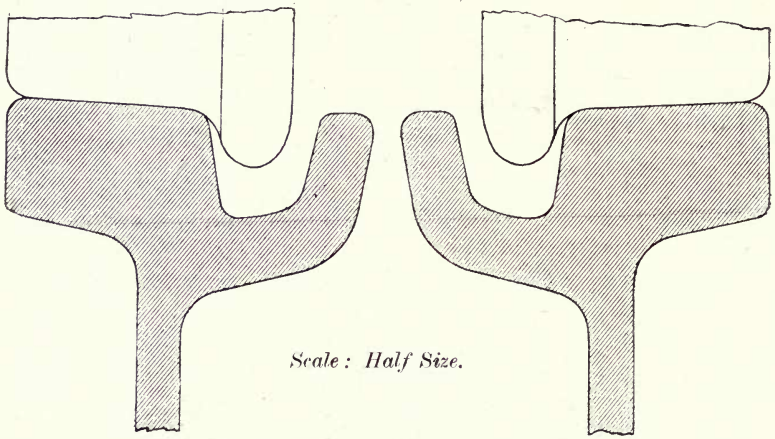



Fig. 79.—New Tyres and Rails at rest on straight Track.

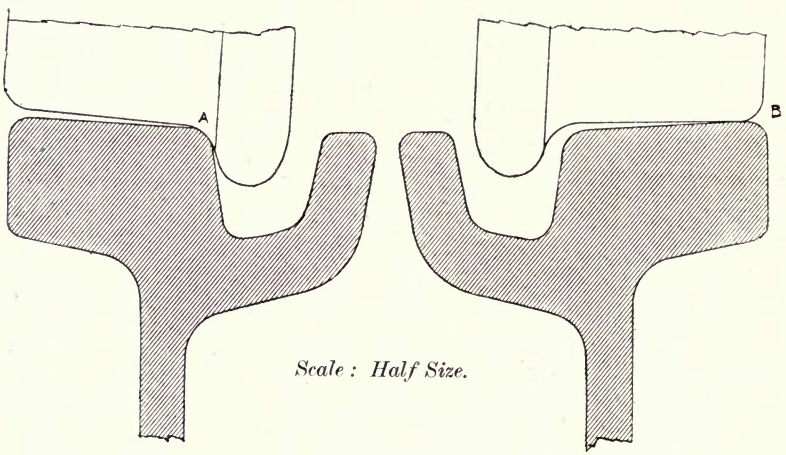



Fig. 80.—New Tyres and Rails in Motion on straight Track.

is generally somewhat lower than the other, with the result that the car gravitates to the low sides, as shown in Fig. 80 (*i.e.*, the low wheel A rides on its throat or largest diameter, whilst the higher wheel B rides on

its outer edge or smallest diameter), and keeps in this position until the wheel riding on its large diameter outruns its less speedy mate and the car swings back into normal position, only to gravitate again to the low side and start a recurrence of the above described side action, which continues as long as the car is in

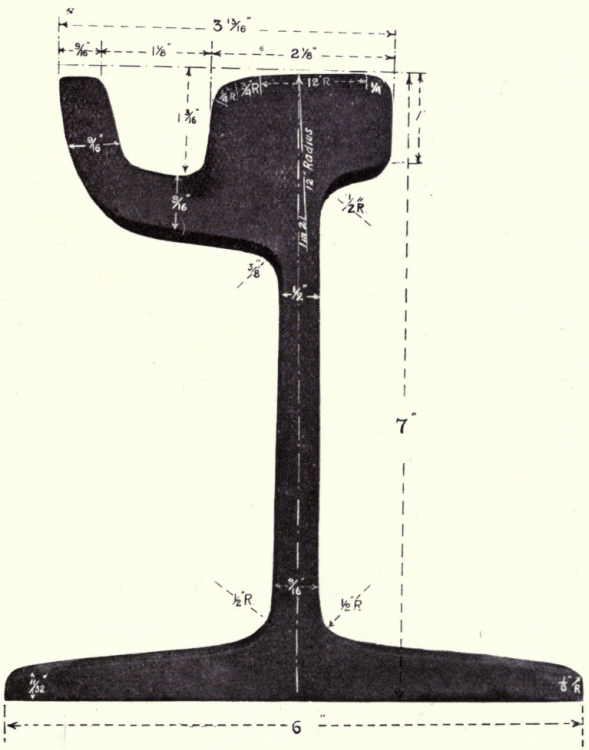



Fig. 81.—Leeds Special Rail (Holt Registered Design).

motion. This action cannot be avoided so long as tramway tracks have to be laid to suit the camber of the road, but the path of the car can be made easier and a better contact provided, as will be shown.

Fig. 81 represents the new rail which was designed by the writer, for the Leeds tramways. It will be observed that it differs from the "Standard" rails in several particulars. The tread is convex, and is inclined

towards the groove, the convexity and inclination being arrived at after comparing some hundreds of gaugings of partly worn rail and tyre sections. In this rail the web has been stiffened, being $\frac{1}{16}$ in. thicker than the web of the British standard rail of equal weight, and in addition is placed beneath the centre of the rail tread, which appears to be the proper place for it.

The writer's reason for these alterations is based upon actual observations on unpaved and partly paved tracks. When the paving is removed from a track, the rail heads are drawn inwards causing a tightening of the gauge in some instances, and a "slackening" in others, without disturbing the rail base, and in each case the load on the rails is non-axial, owing to the unequal bearing of the wheels on the rail head, as shown in the foregoing diagrams. It therefore appears that the rail web requires strengthening, and this may be done as suggested, by placing the web immediately beneath the rail head, and by making the web somewhat thicker, as shown in Fig. 81. This rail has been designed chiefly from the consideration of Leeds conditions; in other systems the conditions may vary slightly as to the curvature of worn rails and tyres, owing to the difference in the ordinary street traffic, the type of rolling stock, and the effect of the different brake blocks used. Brake blocks must undoubtedly have some effect on the curvature or hollowness acquired by the wheel, and indirectly on the rail.

Over 6,000 tons of this section of rail have been laid since January, 1910, on the Leeds tramways, one route alone having carried over 500,000 cars, and, so far, no extrusion of metal has been observed. The wear is regular, the treads retain their convexity of 12 in. radius, and the contact is uniform over the whole tread, as shown in Figs. 78 and 79.

It is interesting to compare railway and tramway

practice in regard to the permanent way. The conditions of tramway permanent way are very similar to those on the railway, but in tramway practice there appears to be an endeavour to differ as much as possible from railway practice, for no apparent reason.

All railway rails are radial topped, the radius being 12 in., the sides of the rail heads are straight, the web is thick and placed beneath the centre of the head, and although the rail heads are not inclined from the horizontal, as in the case of worn tramway rails, the entire rail is inclined from the vertical towards the centre of the track, as shown in Fig. 82, which gives precisely the same result and permits of direct bearing through wheel and rail. Fig. 83 shows the relative positions of the rails on a tramway. It will be seen that although the rail bases are in the same plane, the whole track is "canted" to suit the camber of the street, this, of course, being unavoidable. The rail webs, being at right angles to the rail base, are thus subjected to irregular loading; the rail heads are flat coned, and subjected to the unequal loading previously described. Railway rails wear uniformly and maintain their curvature, and are evidently of the most suitable design, a design which has been evolved from many years of practical experience under all conditions. It therefore follows that tramway practice should, as far as possible, follow railway practice, with due consideration of the peculiar requirements of each.

Another item for consideration in connection with the design of rails is in regard to the height of the check. It is considered by many interested persons that there is some considerable advantage to be gained by keeping the check well down below the level of the tread. But this advantage is more imaginary than real, and on routes where a heavy vehicular traffic makes use of the rails it will be found that the check wears down

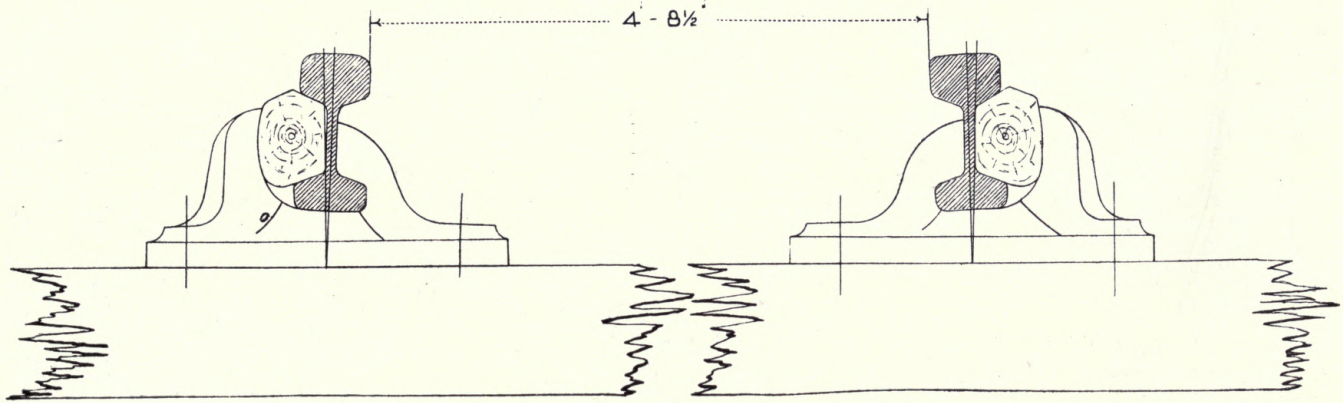



Fig. 82.—B.S.S. No. 100 Bull Head Rail, inclined 1 in 20 inwards from vertical.

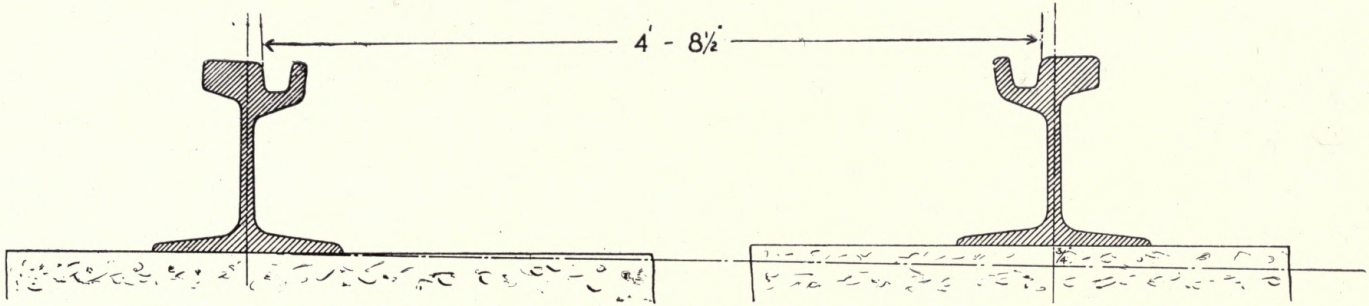



Fig. 83.—B.S.S. No. 4 Girder Rail, inclined 1 in 80 from horizontal.

either at the same rate or more quickly than the tread, as will be seen on referring to the diagrams of worn rails in Fig. 74. Even on routes where there is a light ordinary traffic there does not appear to be any great advantage to be derived from keeping the top of the check much below the tread. One authority considers that when the tread has worn down the upstanding check will be a source of danger to the cross traffic, and he suggests that the check should be depressed $\frac{1}{4}$ in. to start with. This suggestion in no way meets the

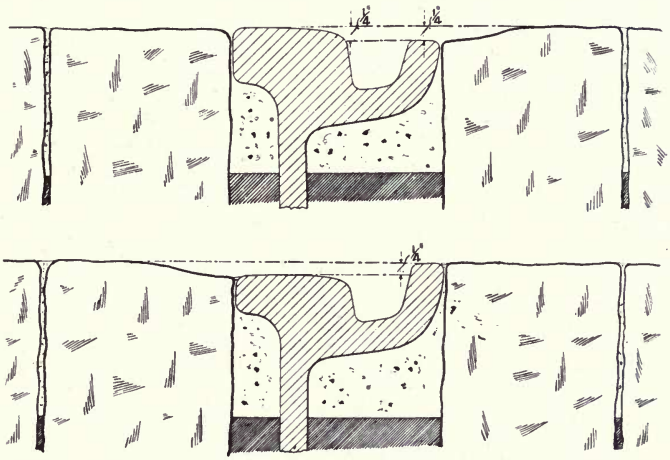


Fig. 84.—Showing Effect of Depression of Check.

case, for on reference to Fig. 84 it will be seen that the depression of the check is equivalent to raising the tread, which will constitute as great a source of danger, if there be any, as the upstanding check. Experience would indicate that $\frac{1}{8}$ in. depression of the check is, as a rule, all that is required. The remaining objects for consideration in rail design are in regard to the width of the flange and the form of joint which it is proposed to adopt. The present rail sections were designed solely for fish-plate joints, and in the writer's opinion are not of the most suitable form for welding purposes. There is a danger that fractures may occur

through the failure of the rail webs on account of an insufficient thickness of metal at this point. It is suggested, therefore, that the web should be stiffened considerably, not only on account of the danger of the molten welding metal charring the web, but also because there is always during the passage of a car a heavy stress present which tends either to overturn the rail or to twist the rail head, particularly where there is any tendency towards looseness. As to the width of the flange, this is far wider than is necessary to give adequate support to the rail, besides increasing the difficulty of rolling the rails at proper heats. Much better shaped flanges would be obtained if the flange width were to be reduced to a maximum of 6 in. for rails 7 in. in depth, with a proportionate increase in the thickness of the web and flanges. By this means the heat of the metal during the rolling process would be retained longer, thus preventing, or at least reducing, the number of torn rail flanges, without the necessity of having the ingots overheated, and at the same time the narrow flanges would be less liable to distortion through shrinkage during cooling. It is advisable that the angles between the head and web should be similar to those on the "Standard" rails, for these are the best angles for fishing purposes, and on all tracks, whether welded or not, a considerable number of fished joints have to be made to couple up to special work.

# CHAPTER X.

## COMPOSITION AND MANUFACTURE OF TRAMWAY RAILS AND RAIL WEAR.

After carefully examining in detail some thousands of tons of worn tramway rails which have been removed from electric tramway tracks during the past ten years, the writer has become convinced that the modern high carbon basic Bessemer steel rail is in many respects inferior to the low carbon rail which preceded it. It is the writer's opinion that tramway rails should be more carefully manufactured from a much superior quality of steel in order to withstand the combined effect of high speeds, heavy vehicular traffic, frequent braking, steep grades, small heavily loaded wheels, and the gritty condition of the rails. The earlier low carbon rail, with its fairly high percentage of manganese, was not such a soft rail as is generally supposed ; and although lighter and smaller in design, it was considerably more durable than the more recent high carbon rail of the standard composition. These earlier rails were of a more uniform structure throughout and more homogeneous, as will be seen on referring to the photographs shown in Fig. 85. These are sulphur prints taken from polished sections cut from rails rolled 15 years ago, which have carried from 20 to 30 million tons of tramway car traffic at considerable speeds.

The durability of the higher carbon basic Bessemer rails, of standard composition, which have come before the writer's notice, has been far from satisfactory, and the maximum traffic recorded up to the present on such rails before replacement has become necessary is

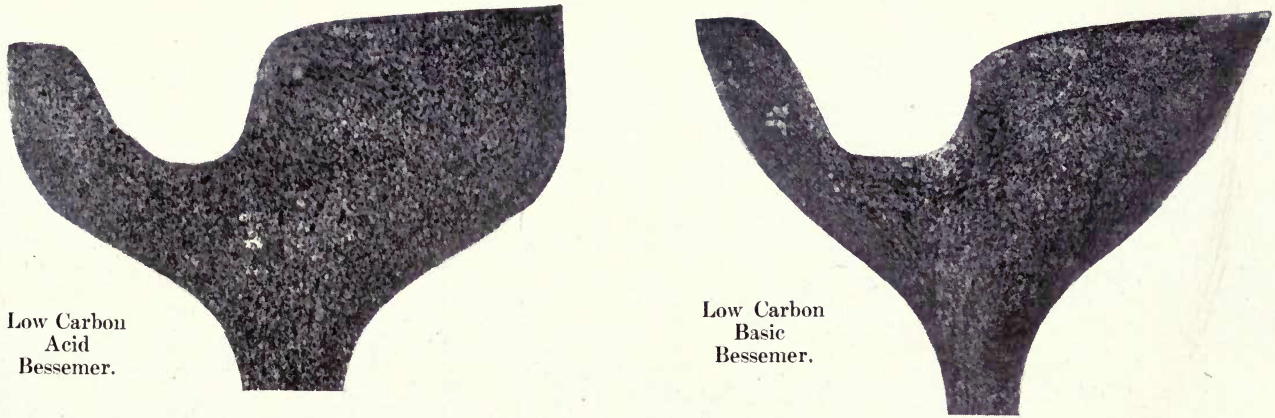



Fig. 85.—Sulphur Prints of old low Carbon Rails, showing homogeneous Structure.

Basic Bessemer Steel, B.S. Specification. Acid Bessemer Rail to B.S. Specification.

Fig. 86.– Sulphur Prints of high Carbon Rails, showing Segregations, Piping, and Unsoundness.

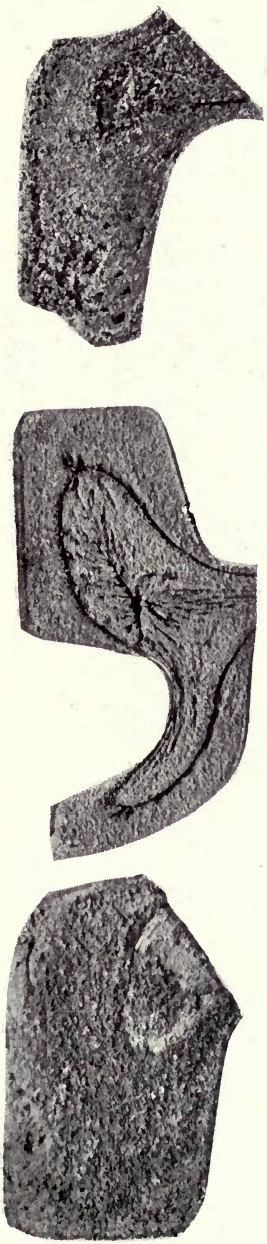
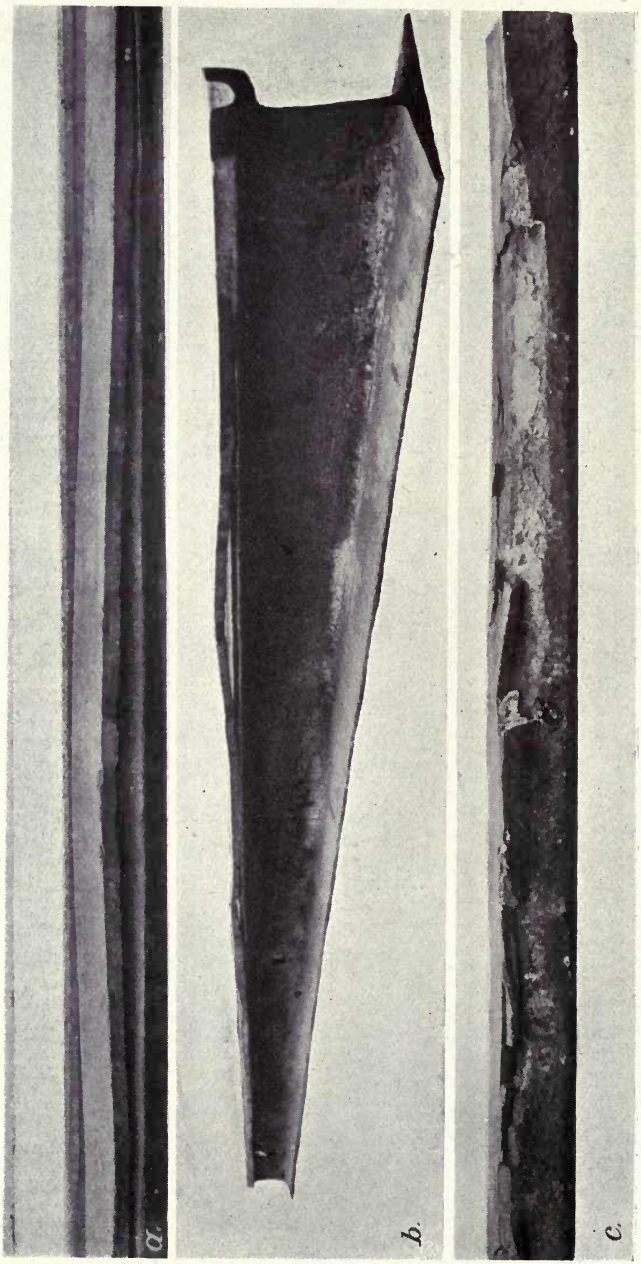
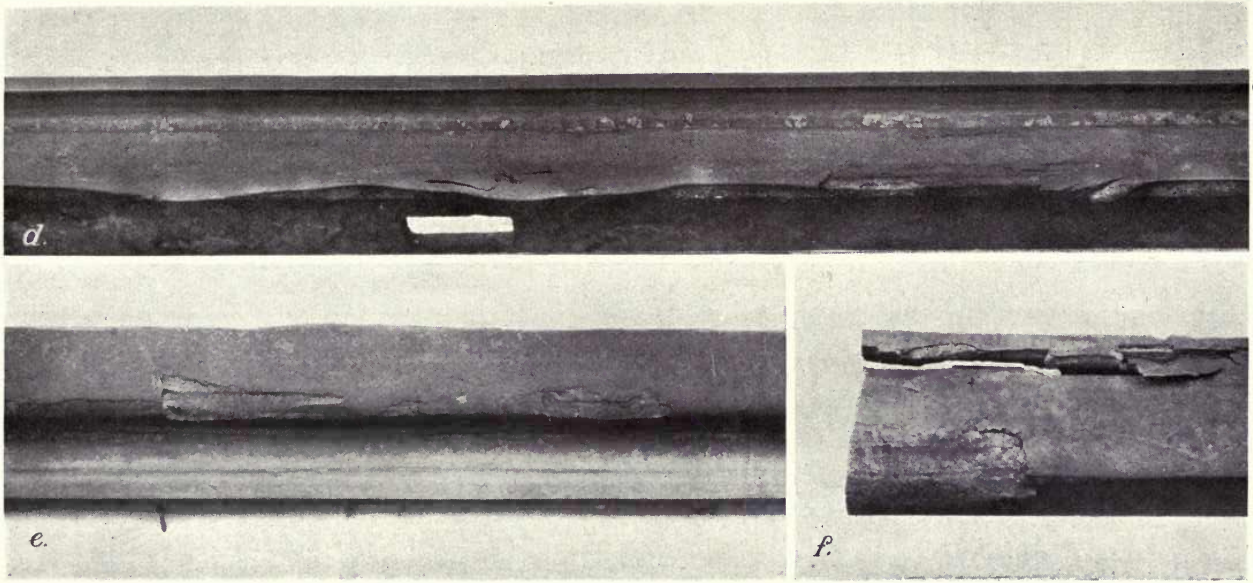


Fig. 87.—Etched Specimens high Carbon Basic Bessemer Rails, showing much Segregation and Unsoundness.

about 27 million tons. It will be observed, on referring to Fig. 86, that the structure of the steel, as revealed by the sulphur print test and by the etchings shown in Fig. 87, is anything but satisfactory. It is particularly noticeable on the Leeds tramways that the basic Bessemer steel of standard composition not only wears more rapidly and unevenly, but it extrudes, laminates, cracks, and the surface peels off, as shown in Fig. 88. The writer does not intend to convey the idea that a mere change in the chemical composition is responsible for this difference in quality and structure, and for the defects shown in the illustrations referred to. It is suggested that the earlier rails were more carefully and regularly rolled at lower and more even temperatures, which was conducive to a closer structure of the steel. There have been many improvements in the manufacture of tramway rails during the past 10 years, but until quite recently such improvements have been more with a view to increasing the output of the works and decreasing the cost of


a.
b.
c.




(*a* and *b*) Show the entire stripping of the head of 20 ft. 0 in. rail, due to being made from a badly-piped ingot.
(*c*. and *d*, *f*) Show the battering, extrusion, exfoliation, and total collapse of the heads of two rails; in (*c*) the presence of slag is easily detected. (*e*) Shows a case of scabbing which is very common.

Fig. 88.—Defective Rails taken from different Tracks, illustrating Faults found in Basic Bessemer Steels of Standard Quality.

production than with the object of improving the quality of tram rail steel.

Tramway engineers have not, until recently, paid much attention to the relation between the composition and manufacture of the steel and the wear of the rails, consequently they have not been in a position to give to the manufacturers such information as would enable them to produce steel suitable for the purpose. At the same time, it is evident that metallurgists and steel experts have not exactly conceived the necessity for a superior quality of steel for the purpose of rail manufacture. The following excerpt from "Steel, its Varieties, Properties, and Manufacture," by Messrs. Greenwood and Sexton, conveys a fairly accurate idea of the esteem in which rail steel is held. The authors refer to the growing popularity of the open hearth steel for all purposes, "whilst the Bessemer process is falling back, and is likely in future only to be used for rails and similar articles where the output required is very large, the price low, and *absolute uniformity of composition is not essential.*" Quite accidentally the authors of this excellent little treatise have expressed the prevailing opinion in regard to the quality of steel which is suitable for rails in general, and tramway rails in particular.

As the wear of tramway rails is so unsatisfactory, and they are subjected to so many different influences which are conducive to excessive rail wear, it is evident that the question of a suitable quality of steel for tramway purposes should receive an early and exhaustive investigation. At the recent conference of the Municipal Tramways Association at Glasgow, Mr. H. Mattinson, in his report on "Tramway Track Construction and Maintenance," referred to the quality of rail steel, and observed that "the percentage of the cost of the rail, allowing its scrap value, is only about 20 per

cent. of the cost of reconstruction, yet the rail alone is the determining factor in the life of the track. Too much attention cannot, therefore, be given to this question, and the very best steel procurable for this purpose is the most economical." Mr. Mattinson further stated that the "composition of the steel given in the British standard specification cannot be classed as a high quality steel, and is by no means of a grade suitable for electric traction." Actual experience on heavily worked systems bears out the accuracy of these statements. It will be generally admitted, however, that the preparation of a standard specification for tram rail steel, suitable for the various ores, processes, and works, is a very difficult matter to arrange. Over 40 years ago the late Sir John Fowler stated at the Institution of Civil Engineers that "no rule could be laid down for the manufacture of rails which would be applicable to all localities." In 1889, at the same institution, the late Sir Lowthian Bell said "that he had tabulated many hundreds of specimens according to the quantity of metals and metaloids contained in the rail, and there was no kind of harmony between weakness and great purity, and, on the other side, there was no harmony between great purity and great strength. He had come to the conclusion, therefore, that great care was necessary in forming any decision too rapidly on all subjects connected with rails." He further stated that "with regard to manufacturers aiming at any particular constitution of rails, that was a much more difficult question. When it was conceived that into a great cauldron about 15 tons of metal were poured, and that in 15 minutes the whole of that metal had been converted into Bessemer steel, it would seem that it was almost impossible to calculate with any degree of nicety the character of the product."

So recently as the Engineering Conference of 1907, such eminent engineers as Mr. Alex Ross, Mr. R. Price Williams, Mr. C. P. Sandberg, and others, were unanimous in their remarks to the effect that a universal specification or composition for rails which will suit all cases cannot be satisfactorily arrived at. "The varying conditions, such as ores available, processes of manufacture, weight of the rails, climatic and traffic conditions, differ to a great extent in every case, and all of them should be taken into account in order to obtain the best results." Notwithstanding these convincing statements in regard to the impossibility of preparing a standard specification for rail steel, many thousands of tons of tramway rails are purchased annually on the understanding that they are manufactured in accordance with the requirements of the Engineering Standards Committee; it being considered that the steel is the best obtainable for the purpose. This is not so, however, and it is not to be expected that steel of a uniform and high-grade quality, suitable for withstanding the extraordinary effects of tramcar and vehicular traffic, will be obtained from the meagre metallurgical data given in the standard specification, which merely consists of a hypothetical analysis suitable for Bessemer steel of ordinary quality, but which in no way guarantees the production of a steel of equal quality and hardness by the other "approved processes" referred to.

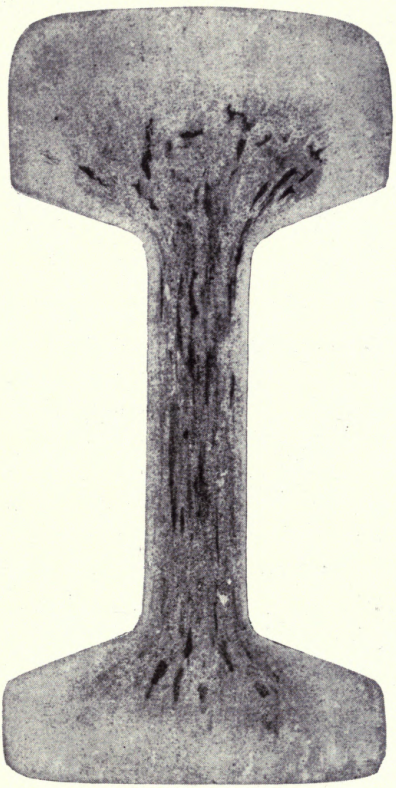
The only data given in the standard specification which may be said to have direct bearing on the metallurgical aspect is the first clause in the specification which reads, that "The steel for the rails shall be of the best quality made by the acid Bessemer, basic Bessemer, or other approved process and on analysis shall show that in chemical composition it conforms to the following limits :

| | Per cent. |
|---|---|
| Carbon | 0·40 to 0·55 |
| Manganese | 0·70 to 1·0 |
| Silicon | not to exceed 0·1 |
| Sulphur | „ „ 0·08 |
| Phosphorus | „ „ 0·08 |

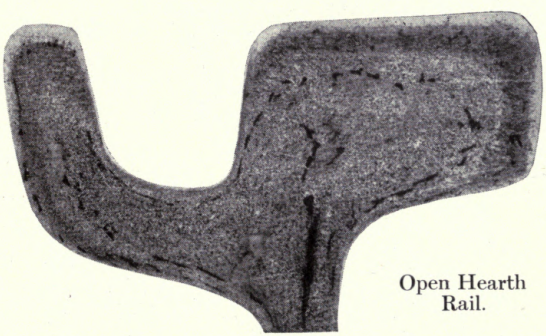
Basic Bessemer and acid Bessemer are two very different processes, and the open hearth process requires a considerably revised chemical composition in order to produce a steel of equal hardness to that obtained by the Bessemer processes to the standard analysis. For instance, the carbon content alone would have to be increased to something like 0·5 to 0·65. Then again, another difficulty lies in the fact that the different results obtained by individual manufacturers may be greater than the general differences in the processes. It is suggested, therefore, that a much more comprehensive specification should be prepared giving, in regard to the chemical composition, such typical analysis as will, within certain limits, be a guide for the production of a steel of equal hardness by the different processes of manufacture.

It is evident that in future much more attention will have to be given to the actual manufacture of the steel. The writer is of opinion that careful metallurgical supervision is required, in addition to the testing and inspection of the finished rails by competent engineers. For the purpose of guiding these inspectors, sound rules should be laid down relating to the timing of the various operations and stages in the manufacture of the rails, and the temperatures which have to be maintained from the casting of the ingots to the completion of the rolling operation. In the past there has been too little attention paid to these important details, and in the majority of cases there has been merely a superficial inspection, and a slipshod method of getting through easy physical tests has sufficed.

The question whether the Bessemer processes are suitable for the production of a really high-grade steel of uniform quality is one which requires very careful consideration, and in any case immediate steps should be taken to ascertain to what extent these earlier methods of steel production may be utilised more satisfactorily. There is a very decided opinion amongst experts that the open hearth steels will give much better results than the Bessemer varieties ; but it must not be imagined that a mere change of the process of manufacture will remedy all the defects and ills from which tramway rails suffer. According to one authority, " the open hearth furnace is too slow in operation to produce rail steel at an economical price, and the output is intermittent and not suited to the continuous operation of a rail mill." On the other hand, the Bessemer processes are said to be wasteful. The Bessemer process of manufacture is cheaper, but the open hearth steels are said to be more reliable. Although it would appear that the open hearth steels are being more generally used, and that the steel is more homogeneous and of a more uniform composition when carefully made ; still it is a fact that, speaking generally, the careless manufacture of steel by this process may have far worse results than the careful production of steel by a supposedly inferior process. The personal equation enters into both cases to a very large extent, and the ideal specification should, as previously stated, contain rules for the guidance of the inspectors, who should have some competent knowledge of steel manufacture. Fig. 89 shows sulphur prints of a tramway rail and a railway rail both made by the open hearth process, and it is evident that there is much segregation and unsoundness. This confirms the assertion that it is necessary for the entire process of manufacture to be under careful supervision. Generally speaking,



Open Hearth Rail.



Open Hearth Rail.

Carbon ·50%, Silicon ·04%, Sulphur ·041%, Phosphorus ·005%, Manganese, ·75%,

Fig. 89.—Showing Unsoundness in Open Hearth Steel Rails.

if the best and most economical results are to be obtained from the open hearth process, it will have to be carefully made in a similar manner to tyre and axle steel. If carelessly made, and with very large ingots, excessive segregation is often found ; for example, the carbon in an ingot may vary from 0·50 to 1·0 per cent., with the result that very uneven results may be obtained. The writer has observed that the earlier low carbon rails with a fairly high manganese content have proved themselves to be considerably more durable than the more modern rails with a lower percentage of manganese ; but it must not be imagined that he advocates reverting to the earlier composition of steel, even if it could be so well made as formerly, although a somewhat lower percentage of carbon and a higher percentage of manganese would facilitate the cleaner rolling of difficult sections. A very much superior quality of steel is required for this purpose, and the maximum load of 40,000,000 tons, which the writer has referred to as having been carried by the low carbon rails, cannot by any means be considered satisfactory from a tramway point of view. When it is considered that the replacement of the rail is a very costly operation necessitating the entire reconstruction of the track, it will be obvious that a harder, tougher, and more homogeneous steel is required.

There is a tendency for engineers to increase the proportion of carbon in their steel with a view to obtaining harder rails ; but it by no means follows that a rail which is glass hard will of necessity be a very durable rail, and there is a certain element of danger arising out of indiscriminate experiments of this kind, that is danger to the rail itself. One very important reason for keeping the carbon down to ordinary limits is in connection with welded joints. There is ample evidence pointing to the fact that the welded joint has

come to stay, and, as the writer has previously indicated, its requirements should be fully considered in the drafting of a specification for the design and manufacture of tramway rails. The effect of a very high carbon in rail steel, say above 0·5 per cent., is detrimental to the making of a true butt weld by the Thermit process of rail welding. It is said by Thermit, Limited, that such steel can only be welded when, between the fluid and solid stages, the metal remains in a state such that it can amalgamate without actually becoming fluid. The more carbon there is in steel, the shorter the period in which the metal remains in this intermediate stage, and with very high carbon steels it becomes so restricted that amalgamation only takes place in the liquid stage. With the increase of the carbon there is, at the same time, a lowering of the chilling point of the steel and an increased risk that the material, in consequence of being heated by the Thermit slag, will not amalgamate, but will simply be washed away. From this point of view alone it is evident that other hardening agents should be carefully considered on their merits, more particularly so as the wear on the modern high carbon steel rail has not realised the high standard of excellence which was predicted for it.

Whether the open hearth processes will ultimately supersede the Bessemer processes remains to be seen; but it is evident from a fairly lengthy experience of silicon steel on both tramways and railways, that the improvements in steel manufacture patented by the late Mr. C. P. Sandberg, M.Inst.C.E., have, in a manner of speaking, "set back the clock," and given the Bessemer processes—as far as regards rail manufacture—a new lease of life. The addition of silicon, by this process, has the effect of increasing the life of the rail by fully 33 per cent., as will be seen on referring to the repro-

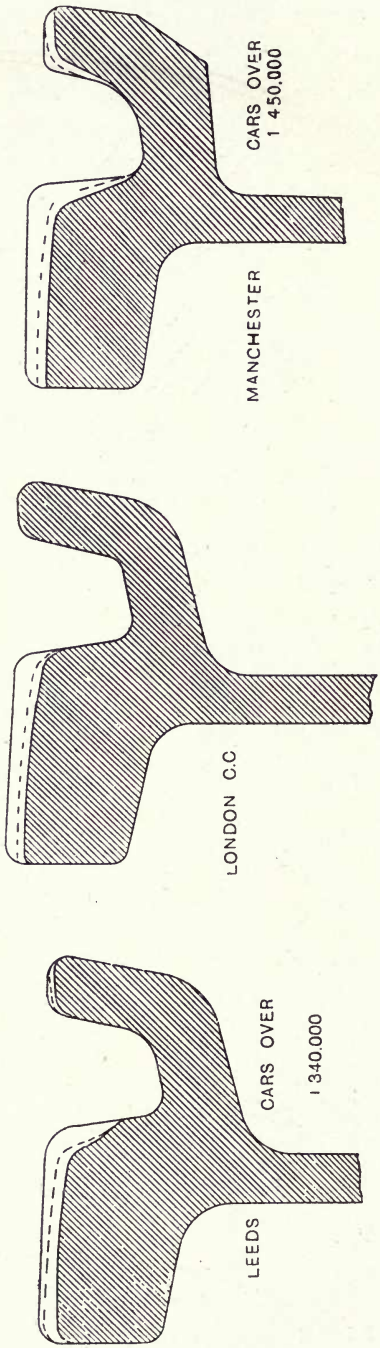



Fig. 90.—Comparative Wear of Rails.

duction of the diagrams (Fig. 90) which were presented before the Municipal Tramways Association at the conference at Glasgow in 1911.* In connection with this quality of steel it is interesting to note that nearly 1,000,000 tons have been used on tramways and railways since 1905.

Silicon steel may be made by any of the ordinary processes, and consists chiefly in the elimination of the silicon in the metal during the process of conversion, a known proportion being added subsequently in the form of ferro-silicon or silico-speigel.

By Mr. Sandberg's process the silicon is added to the charge after the purification of the crude steel, in such proportion that the finished steel may contain from 0·2 per cent. to 0·50 per cent.

* *Vide The Tramway and Railway World*, October, 1911.

The effect of the added silicon is to toughen the steel instead of making it brittle, as is the case when the silicon is left in from the pig iron. "Silicon left in the charge is generally an indication that the metal has been blown too hot, which is well known to lead to great irregularity in the finished steel." Silicon occurs in two distinct forms in steel: firstly, as silicate or slag, which has a decidedly injurious effect upon the steel; and secondly, as silicide of iron, which alloys with the metal and imparts useful and valuable properties to the steel. The effect of the added silicon is claimed to be four-fold: First, it completely eliminates oxide, thus producing a metal less easily corroded. Secondly, the elimination of the oxide is accompanied by a marked increase in the fluidity of the steel, thus enabling the entangled slag to rise to the surface. Thirdly, the combination of silicon with oxygen takes place with a considerable evolution of heat which tends to maintain the temperature of the metal, and thus allows a longer time for the separation of the slag. Fourthly, an excess of silicon over and above that required for the deoxidation alloys with the steel and produces a metal which is much stronger than ordinary steel, while at the same time it remains absolutely free from brittleness. That these claims have been amply substantiated is evident from the large quantity of Sandberg steel which has been used within the six years since its introduction. The diagrams shown in Fig. 91 show the rate of wear on this quality steel as compared with the ordinary basic Bessemer, together with the amount of traffic carried. Fig. 92 shows a section of a Sandberg steel rail, which has been polished and immersed in a strong solution of hydrochloric acid and water for 48 hours. It will be observed that the structure of the steel is perfectly homogeneous, and there are no signs of unsoundness. Fig. 93 shows two specimens, one of standard quality

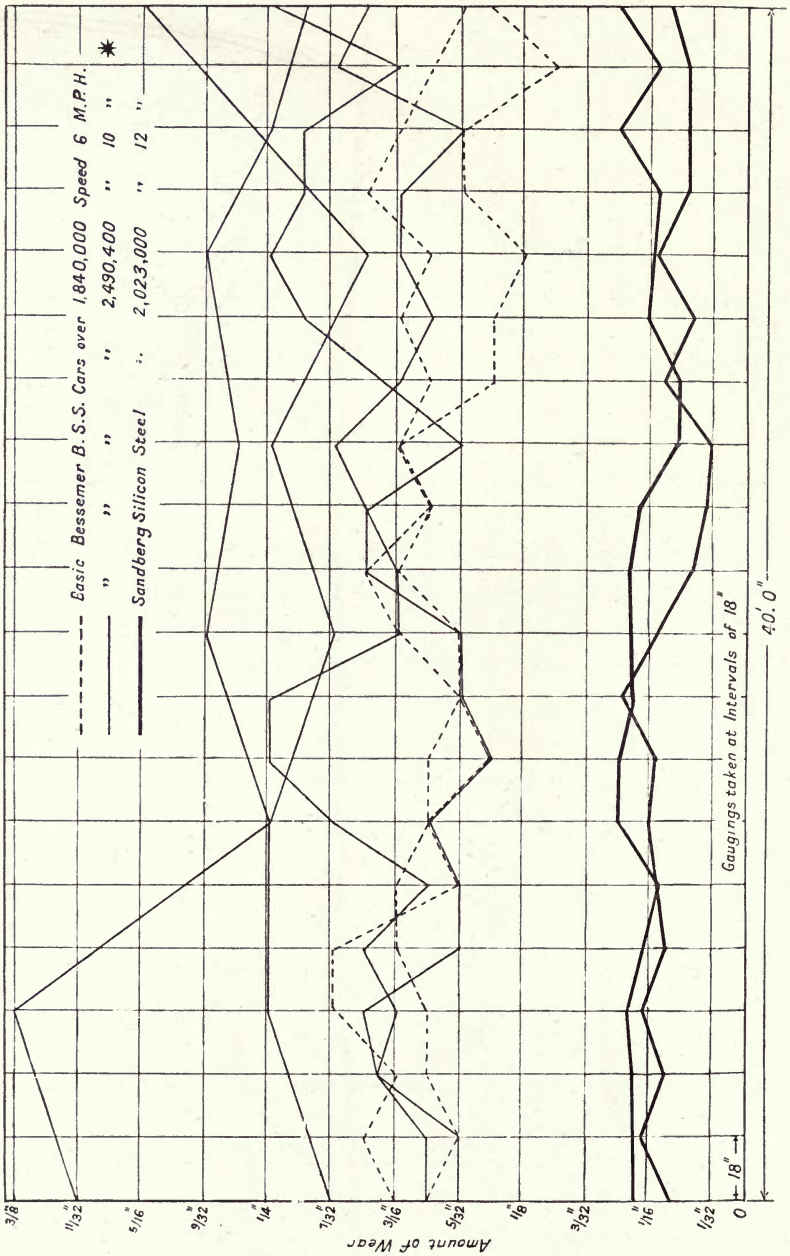



Fig. 91.—Comparative Wear of Rails.

steel, and the other of Sandberg steel, which have been cleaned and immersed in a solution of hydrochloric acid and water for 24 hours, in order to ascertain the density and texture of the metal in the rail tread.

It will be observed that the specimen of Sandberg quality is more dense in structure than the other. These illustrations indicate the difference in the quality of the two steels as revealed by innumerable tests.

The hardness of rails made from this quality of steel

Fig. 92.—Etched Section of Sandberg Rail.

is indicated by the high tensile strength (an average of over 50 tons per square inch being obtained) and the resistance to the impression test. In the latter case the pressure of 50 tons upon a hard steel ball 19 millimetres in diameter only produced an impression 3·5 millimetres deep, whereas the same pressure applied to the ordinary basic Bessemer steel caused an impression 4·5 millimetres deep. Its toughness and resistance to sudden shocks are shown by the fact that it may be bent cold to the sharpest radius without fracture, and it is capable of withstanding a severe drop test.

The following Table shows the actual chemical

Specimen of "Standard" quality steel, immersed for 24 hours.

Specimen of "Sandberg" steel, immersed for 24 hours.

Fig. 93.—Etched Specimens, showing the Difference in the Structure of "Standard" Quality Steel and "Sandberg" Steel.

composition and physical properties of specimens of the steel rails now being used on the Leeds Tramways :—

LEEDS CITY TRAMWAYS.

Makers : Walter Scott, Ltd., Leeds Steel Works.

Basic Bessemer Steel—Mr. C. P. Sandberg's patent process.

| Composition by Analysis. | Tensile Test. | Brinnel Impression Test. | Drop Test. |
|---|---|---|---|
| Manganese . 1·25% | Average stress : 50 tons per square inch. | 50 ton load. | 1 ton tup, 18 ft. drop. |
| Carbon . . ·40% | | 3·5 mm. impression. | |
| Silicon . . ·30% | 20% Elongation. | | Average deflection $1\frac{9}{16}$ in. |
| Sulphur . ·07% | 26% Contraction of Area. | N.B.—On "Standard" quality Basic Bessemer Steel the impression = 4·5 mm. | |
| Phosphorus . ·07% | | | |

Bending test : Two rails selected at random were curved to 15 ft. radius without sign of fracture.

In regard to other hardening and toughening agents, experiments have been made both in this country and in the United States of America with nickel and chromium, and the results are said to be satisfactory as far as regards the increased wearing properties imparted to the rails and the absence of brittleness, but it is said that the cost of such rails is out of all proportion to the benefits gained. Titanium, which has been tried on some American railways, is said to be a very powerful deoxidiser, and that it also removes a portion of the nitrates as well. It is claimed also by the Titanium Manufacturing Company of Pittsburg, that "Titanium prevents brittleness, hence the carbon content of the rail may be materially increased." The analysis of open hearth steel rails which have received this treatment show that the carbon content is generally above 0·8 per cent. Experiments are being made on railways and on at least one tramway system in this country with Titanium treated steel rails, but up to the present no results have been published.

It is well known that rails containing an excess of phosphorus invariably wear well, but the brittleness accompanying the same is seriously detrimental even in tramway rails, as it leads to fractures in handling and bending. In the basic Bessemer process it would be impossible to make use of phosphorus as a hardening agent, on account of the difficulty of stopping the dephosphorisation at such a point as would leave the required amount in the steel. In the acid Bessemer process, with a pig iron containing 0·1 per cent. of phosphorus, which is not affected by the conversion, a regular 0·1 per cent. of phosphorus may be obtained in the steel.

Manganese will harden the metal, and in sufficient quantity it secures a more uniform distribution of the carbon, and on account of its affinity for oxygen it eliminates the oxides of iron formed during the conversion of the steel, and to a certain extent prevents the formation of oxides whilst the steel is being worked into shape. In sufficient quantity manganese arrests the cooling of the steel during the rolling, and thereby obviates the necessity for commencing and completing the operation at excessively high temperatures. For tramway purposes rails may be made considerably harder than railway rails, for there is not the same risk attendant upon the fracture of a rail. It is of rare occurrence for a tramway rail to fracture after it has been laid, and where such a break occurs it is not discernible for some considerable time. It is therefore apparent that the drop test is unnecessarily severe for tramway rails. Generally speaking, rails that will pass through the tensile and impression tests and the straightening at the works, the handling in transit, and the curving and handling on the job, will do well enough for all purposes. It follows, therefore, that the abolition or modification of the drop test, for all but

comparative purposes, will be an advantage, and will permit of the use of harder rails. Probably the best method of increasing the hardness of basic Bessemer tramway rails would be to increase the carbon to about 0·5 per cent., and bring up the manganese to between 1.0 to 1·25 per cent., with approximately ·35 per cent. of silicon obtained by Sandberg's process, and by dispensing with or reducing the drop test.

In conclusion the writer must again insist on the fact that if better rails are to be obtained, a fair price must be paid and the process of manufacture must be carefully followed from start to finish.

## CHAPTER XI.

### THE CORROSION OF TRAMWAY RAILS.

The writer has drawn attention, from time to time, in these chapters, to various causes resulting in rail wear. These may be recapitulated as follow: The speed and weight of the cars, the density of the car service, the design of the rails and the quality of the rail steel, and the nature and weight of the ordinary street traffic. In addition to these more important causes, the rate of wear is undoubtedly influenced to a considerable extent by the frequent use of the brakes and brake sand, the proportion and extent of the gradients, the condition of the wheel tyres, the cleanliness of the rails, and, to a varying extent, by the corrosion of the rail steel. The regular gauging of rails, in all positions, indicates that the rate of wear increases rapidly with the speed of the cars, and that speed is far more destructive to the rails than traffic density; unfortunately it is not possible to express the ratio of the wear in terms of either the speed of the cars or the traffic density on account of the variations caused by the presence or absence of any of the above-mentioned supplementary factors. By observing tracks where the conditions, excepting speed, are almost identical, the writer has noticed in several instances that the number of cars carried on tracks where the speed has not exceeded 10 miles per hour has been double that on tracks over which the cars run at 15 miles per hour and upwards. It is also a notable fact that the wear of rails is more regular where the ordinary street traffic is of a light order. Again, as has been said in previous

chapters (and as illustrated in Fig. 94), there are numerous instances on the larger tramway systems where the rails have become worn out without ever having been run over by the tramway cars; such wear being almost entirely due to the ordinary street traffic.

To turn to the question of rail corrosion, this would appear to be more likely to take effect in damp situations, where the rails are alternately wet and dry, and subjected to an infrequent service of cars. It has been suggested, and with very good reason, too, that the impurities deposited from the atmosphere in many of the great industrial centres may have a deleterious

Fig. 94.—Wear of Tramway Rail entirely due to ordinary Street Traffic.

effect on the rails, and in conjunction with this suggestion the nature of the road mud should receive due consideration, particularly where there is considerable cartage of trade wastes, which drain from the carts on to the track surface.

On railways the rails deteriorate more rapidly in tunnels than in the open air, on account of the presence of sulphurous gases from the locomotives and the moisture which is generally percolating through the walls, the corrosion taking effect over the entire rail-section. In a paper on the "Wear of Steel Rails in Tunnels," presented to the Institution of Civil Engineers in April, 1900, Mr. Thos. Andrews states that in one tunnel 3,000 ft. long the average loss in weight of

rails from corrosion and wear was 2·8 lb. per yard, as compared with an average annual rate of ·324 lb. per yard for rails under the same volume of traffic in the open air.

In a discussion on a paper by Mr. G. Lawford, "The Maintenance of Permanent Way Exposed to the Sea," read before the Permanent Way Institution in 1909, it was stated by Messrs. G. Lawford and Fletcher that there is rapid deterioration of rails, fish plates, and bolts, due to corrosion, when exposed to moisture-laden sea winds. On one particular length of line referred to, the life of the rails is five years less than on other parts of the same line which are not so exposed. According to Mr. Fletcher, similar lengths of rails on the North Eastern Railway are so corroded that the web of rail is reduced in places to $\frac{1}{8}$ in. in thickness, and the whole of the surface of the rails exposed to the north-easterly winds is pitted to an alarming extent (see Fig. 95). It is stated that "this pitting can only be detected with difficulty, except when the rails are wet," and also that the deterioration is almost entirely on the rail which first catches the sea moisture-laden winds. The pit marks are said to be "in clusters, and to be for a long time covered up with a cake of rust, which, when it falls away, reveals a black carbonised blotch on the rail which quickly becomes coated again."

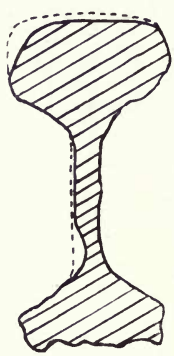


Fig. 95. — Corrosion of Rail exposed to Sea Winds.

In a paper contributed to the Journal of the Tramways and Light Railways Association by Mr. W. Thom, general manager of the Potteries Tramways, the author draws attention to the fact that the wear of the rails is not directly proportionate to the number of cars which have passed over the rails, and he suggests

that the bulk of the extra wear is due to corrosion, and that the difference in the speed of the cars may be ignored. From measurements which Mr. Thom has taken, he infers that the wear due to the passage of 10,600,000 car-tons is ·2279 in. and the loss of metal due to corrosion during the same period is ·0846 in.

To Mr. Thom is due the credit for being the first to attempt to express the rate of corrosion in proportion to the number of years the rails have been in service, but it is improbable that the loss of metal can be satisfactorily accounted for in this manner. As the present writer has indicated, the speed of the cars, the quality of the rail steel, the nature and amount of the ordinary street traffic, etc., are all factors of primary importance, and their effect on the wear of rails is too far-reaching to be ignored. The writer has ascertained from collieries and steelworks that the rails in sidings near to deposits of coal and coke, and those carrying wagons dripping with moisture from these materials, corrode much more rapidly than other rails in the same sidings that are not so exposed. The writer has been observing for a considerable period the effect on the rails of the seep water from a large stack of coal in the tramway permanent way depôt, Leeds. This coal has been stacked to an average height of about 11 ft.; rain water is absorbed and is afterwards discharged in the form of small runnels of a light brown-coloured liquid, which drain into the tramway rails surrounding the stack.

There are two varieties of steel in the track which has received this discharge for a period of 18 months, viz., ordinary basic Bessemer steel and Sandberg basic Bessemer steel. The former variety has corroded away rapidly at each place where the liquid has flowed over the rail tread, as shown in Figs. 96—99. The depth of the corrosion varies: in a number of places

Fig. 96.—Runnels of Liquid between Coal Stack and Rail.

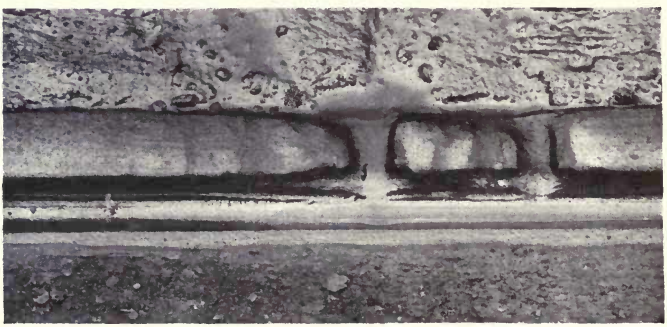


Fig. 97.—Corrosion of Rail Tread where Liquid flows into Groove.

Fig. 98.—Corrosion of Rail Tread where Liquid flows into Groove.

it exceeds $\frac{1}{4}$ in., with variations in width up to several inches, as may be seen in the photographs. The liquid has attacked the Sandberg steel also, but to a far less extent, the maximum depth of the corrosion not exceeding $\frac{1}{64}$ in., and at the same time there are no indications

Fig. 99.—Effect of corrosive Liquid on a Sandberg Steel Rail.
(The corrosion is uniform and mild.)

of irregular pitting. The loss of metal is uniform, as shown in Fig. 99.

The analysis of the liquid is as follows :

| | |
|---|---|
| Water . . . . . | 96·41 per cent. |
| Ferric sulphate . . . . | 2·27 „ |
| Ferrous sulphate . . . . | 0·85 „ |
| Calcium sulphate, etc. . . . | 0·47 „ |
| | 100·00 per cent. |

Note.—The analysis shows this to be a dilute solution of the sulphates of iron, probably formed by the oxidation of the iron pyrites in the coal.

(Signed) Thos. Fairley, *Analyst.*

This case is an exceptional one, of course, but it clearly indicates the susceptibility of ordinary rail steel to corrosive influences, and as there are many indications of corrosion and pitting to be observed on tramway rails, it is evident that the question of rail corrosion will have to receive more attention in the future.

## CHAPTER XII.

### TRACK PAVING.

The paving is the most expensive item in both the construction and maintenance of a tramway, and the promoters of tramways consider it an injustice that they should be compelled to provide and maintain an expensive pavement for the sole use of the ordinary vehicular traffic, in addition to being mulct heavily in regard to the ordinary highways rate. On the other hand, highways authorities contend that the ordinary vehicular traffic is swept off that part of the roadway wherein the rails are laid, and is concentrated at the sides thereof, causing excessive wear and tear. It is further alleged that, although the cars do not actually make use of the paving, the vibration which is set up by the passage of heavy cars is sufficient in time to loosen both the rails and the paving. One authority states that such repairs are inevitable, and that more damage is done to the setts by the frequent repairs than by ordinary wear and tear. In exceptionally busy thoroughfares in the centre of large towns there are undoubtedly some few instances where the track is monopolised by the tramway cars, but on other parts of tramway tracks it will be found that full advantage is taken of the reduction in the tractive effort afforded by the rails. Figs. 100—103 are examples of the wear which takes place on the track paving on all systems. This is entirely due to the ordinary street traffic, and the concentrated wear due to both the wheels and the horses' hoofs may be easily discerned. Figs. 102 and 103 are groups of setts which have been taken from

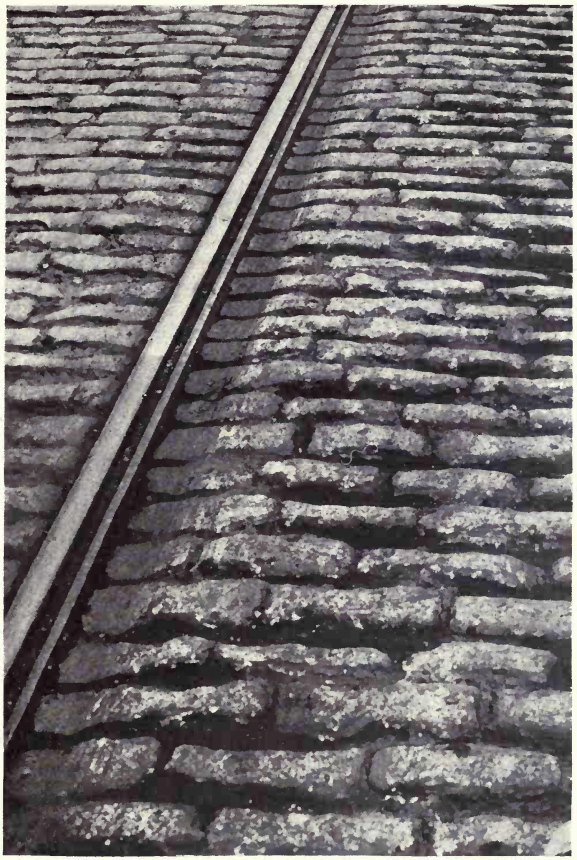


Fig. 100.—Showing Wear due to vehicular Traffic alongside of Rail.

Fig. 101.—Showing Track Pavement crushed by heavy vehicular Traffic.

alongside the rails, and from the centres of different tracks. With reference to the suggestion that the vibration of the rails is responsible for the bulk of track paving repairs, and that such repairs are inevitable, it must be pointed out that a very considerable amount of damage is done to the paving of tramway tracks by the ordinary street traffic, and it is not at all an uncommon occurrence for paving repairs to be executed on tracks where there is little or no service, and where the

Fig. 102.—Typical worn Granite Setts taken from alongside of the Rails

Fig. 103—Typical worn Granite Setts taken from between Rails.

rails are not moving in the slightest degree. At the same time, it must be admitted that very considerable quantities of paving repairs due to loose rails are executed annually on nearly all systems, but this is not by any means due to the inevitability of such repairs. If the loosening of the rail was inevitable, it would naturally follow that the whole of the paving adjoining the rails would become loose in due course, whereas in the worst of tracks there will be found very considerable lengths of paving and rails which have not been disturbed. The loose rails and paving referred to are

not caused by the inevitable loosening of the rails, but to the fact that they have never been properly laid. Well-laid rails do not work loose, and subsequent signs of looseness are entirely due to the development of incipient flaws.

As the writer has shown in previous chapters, the looseness of rails is due to one of two causes, either the concrete foundations are fractured, or the rails have not been properly packed before being paved in. In the latter case trouble may be generally traced to the expansion and contraction of the rails after they have been packed. As the writer has remarked before, the rails may have been carefully packed at the time, but the supervision has ended there, and the subsequent movement in the rails due to the variations in the temperature has been sufficient to destroy the contact between rail and packing. If loose rails and paving are to be avoided it is necessary that every yard of rail should be carefully sounded by a responsible person immediately before being paved in, and all doubtful places should be carefully repacked. In order to further minimise the risk of loose rails and paving, it is advisable that the rails should not be packed for more than a rail length in front of each paving gang, and the effect of the changes of temperature may be further neutralised by commencing the paving operations in several different places on the same track simultaneously, for example at each end of a given length and in the middle. The writer has frequently noticed that no trouble is ever experienced on reconstructed tracks which have been entirely relaid during the night in busy thoroughfares, and this notwithstanding the fact that such tracks have been in service on the following morning. This should prove conclusively that with a uniform temperature, and where the tracks are paved immediately, trouble from loose rails and paving may

be overcome provided that the concrete foundations are unfractured.

It is not to be expected that the promoters of a tramway should be freed from their obligations to reinstate paving setts which have been disturbed by the looseness or vibration of the rails, and which may be readily traced. But it is reasonable to anticipate an amendment of the archaic Tramways Act of 1870, which insists that the rails shall be kept level with the surface of the paving. In the days of the horse-drawn tramcars there was a certain amount of justification for this provision, but to-day it is not reasonable to insist that the promoters should bear the cost of the wear and tear of the sett paving which is caused by the ordinary vehicular traffic.

Notwithstanding the injustice of the existing legislation, the prospect of any alleviation appears to be remote, and taking into consideration the amount of wear that takes place on the paving of all tramway tracks, it is necessary that the closest attention should be given to the quality of the granite, the size and dressing of the setts, and the manner of laying the same. It is false economy to execute the track paving with roughly dressed setts of inferior quality. So long as there are rails in the road, and in the absence of statutory powers limiting the use of the track by other vehicles, the track paving will be subjected to more than its share of the ordinary street traffic on account of the decreased tractive effort offered by the surface of the rails. In many instances it may not be possible for more than one pair of wheels on a four-wheel vehicle to make use of the rails, and in the case of some two-wheel carts perhaps only one wheel may ride on a rail, but no doubt a certain advantage is gained in each case, and in the course of a short time

the other wheels form for themselves a smooth path alongside the rails, as may be seen in Fig 100.

Roughly-dressed setts very soon accomplish their own destruction, for the constant passage of heavy vehicles, which pound along from one sett to another, rapidly pulverise soft setts of this type, and split the harder varieties (see Fig. 101). For tramway purposes where there is any vehicular traffic worthy of note, it is necessary that well-dressed setts of good serviceable granite should be used. Such may be obtained from Bonawe, Trevor, Aberdeen, Mount Sorrell, Enderby, Llandbedrog, Dalbeattie, Newry, Penmaenmawr, and other quarries. These granites vary in hardness, and should be selected after due consideration of the weight and density of the vehicular traffic and the gradients and other local conditions. For instance, Mount Sorrell, Trevor, and Aberdeen are each capable of sustaining very heavy traffic, but on appreciable gradients with tight-jointed setts they would become too slippery to afford a satisfactory foothold for horses drawing heavy loads. For steep gradients an excellent foothold is afforded by Dalbeattie and Newry granites, which are of large grain and contain plenty of white mica which crumbles away, leaving the sharp edges of the quartz and spar crystals exposed, but in consequence of which they are not so durable as the other varieties mentioned.

Again, where exceptionally heavy loads are to be borne by the paving, it is necessary that the granite should combine great hardness with toughness and non-slipperiness. These qualities are rarely found in one stone, and so far the writer has obtained the most satisfactory results in such places from the use of Bonawe granite. This is a grey granite of fine texture, containing just sufficient white mica to keep the edges of the crystals exposed and the surface of the setts sharp.

Fig. 104.—Track paved with Bonawe Granite Setts after Four Years, under heavy vehicular Traffic.

Fig. 105.—Showing Wedge-shaped Setts.

Fig. 104 shows a track paved with Bonawe granite, which has carried heavy road traffic for four years. Particular attention should be paid to the dressing of the setts. Badly-dressed setts are not so durable as well-dressed setts, and it will be found to be more economical eventually to pay the difference in the cost of the better-dressed ones. Setts should be dressed so that they may be paved with a tight joint, and without the use of racking. The setts should be free from bulges, and at the same time they should not be wedge shaped or undercut to any extent, as shown in Fig. 105. Each sett should be dressed and squared on all its faces, its ends should be parallel and square, and the top and bed should be level (see Fig. 106). Setts should not be less than four inches in width, and no variation greater than one-quarter of an inch under or over the specified sizes should be allowed. For tramway purposes the length of the setts should vary between 6 in. and 9 in. If the setts are made longer than this it is not possible to pave them with the half-inch of camber which is necessary to free the paving of standing water. Again, long setts are liable to rock when cambered between two rails. The depth of the setts will depend entirely upon the form of construction adopted. The writer has invariably obtained the best results from the use of setts not exceeding 5 in. in depth, paved upon a half-inch bed of cement and sand composition, as shown in the chapter on track design.

In busy parts of a system where it is necessary to minimise the noise caused by the traffic as much as possible, and where the traffic is too heavy for wood paving, very excellent results may be obtained by laying "nidged" setts. These are setts carefully dressed and squared, and finished off on the surface by masons, as shown in Figs. 107—110. Granite setts of this description are naturally much more expensive

Fig. 106.—Showing Square-dressed Setts.

Fig. 107.—Nidged Granite Setts (Unpaved).

Fig. 108.—Nidged Bonawe Granite Paving, Leeds Tramways.
(A few courses of ordinary sett paving are to be seen in the foreground.)

than the best dressed setts of ordinary quality, and are only recommended for special purposes.

Fig. 109.—Nidged Granite Setts (Unpaved).

It has been stated that wood blocks do not form a good material for tramway paving, and that a tramway

Fig. 110.—Showing Nidged Bonawe Granite Sett Paving.

engineer seldom lays them from choice. There is no disputing the fact that much trouble has been

experienced with wood paving on tramways, but with care in the selection and treatment of the timber and in laying the blocks, very satisfactory results may be obtained. The writer has continually observed on old lines that the short lengths of track which have been paved with wood opposite places of worship are invariably in much better condition than the remainder of the track. That is to say, whilst the short rails may be "hogged" and loose in the granite paved portions, they are firm and straight in the wood pavement. No doubt much of this is due to the presence of the concrete above the base of the rail, but at the same time the wood must necessarily absorb a considerable amount of vibration. The swelling of wood pavements has in some cases

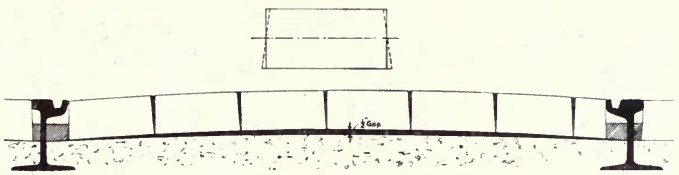


Fig. 111.—Swollen Wood Pavement caused by Contraction of the Surface of the Blocks in Hot Weather.

caused the track to get out of gauge, and much expense has been incurred in lowering high wood paving. The swelling of wood paving frequently takes place during the dry weather, whilst the wood is contracting on the surface. This is paradoxical, but none the less true. It may be taken that there is a neutral axis in each block, and that when the surface of the block contracts to any extent the base of the block expands, as shown in Fig. 111. The presence of detritus in the surface cracks prevents the return of the block to its original position.

The writer's experience of wood-block paving is that soft wood pavements are quite as lasting as those made with hard woods, and the rate of wear is much more uniform. Hard wood blocks wear slippery, and owing

to the resistance they offer to the pounding of horse hoofs they become badly rounded, as shown in Figs. 112 and 113, thereby losing all claim to the resiliency and

Fig. 112.—Showing Wear on Hard Wood Block Pavement.

noiselessness which wood pavements should possess. Soft wood paving is only one-half the cost of hard wood ; which is a very important item for considera-

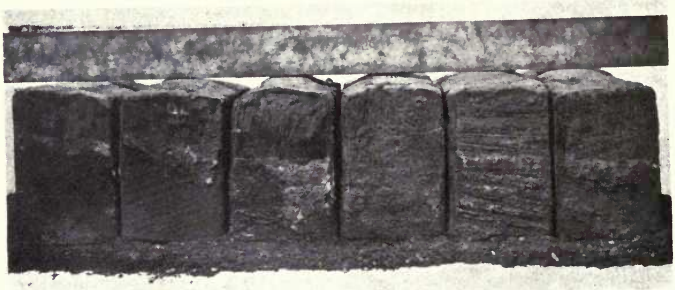


Fig. 113.—Showing Wear on Hard Wood Blocks.

tion, particularly so as neither the hard wood nor the soft wood have any residual value worth mentioning. The writer has obtained the best results from the use of Archangel redwood, creosoted to the extent of 12 lb.

per cubic foot, under a pressure of 60 lb. per square inch. Fig. 114 shows a soft wood pavement which has been in service for 10 years under a fairly heavy vehicular traffic. Fig. 115 shows the wear on soft-wood blocks removed from the track.

Fig. 114.—Showing Wear on Soft Wood Paving.

For tramway purposes it is advisable that all granite setts should be paved upon a bed of moist cement and sand in the proportion of about four to one. This, after

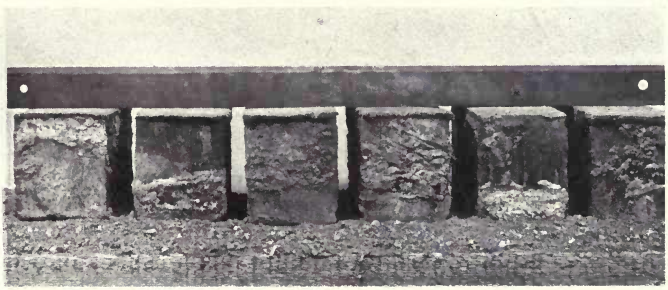


Fig. 115.—Showing Wear on Soft Wood Blocks.

it has set, will tend to lesson any tendency for water to surge beneath the setts in the case of looseness developing in either the rails or the paving. It is a mistake to suppose that a sand paving bed affords any advantage in the nature of a cushion beneath the paving, after the

setts have been rammed; the bed is perfectly hard and unyielding, and in any case it is undesirable to have a resilient cushion between the setts and the foundation. If resiliency is desired it should be obtained at the surface of the paving, not beneath it. For track purposes the writer has found it advisable to lay wood blocks in precisely the same manner as the stone paving in order to minimise the effect of expansion and contraction. The wood blocks are laid upon the pounded floating, carefully rammed and grouted, as described hereafter.

Paving of all descriptions is liable to failure unless it is properly laid under competent supervision. Paviors' work is little understood by the average man in charge of either street works or track work, and whilst much attention is paid to the coursing, gauging, lining, and levelling of the work generally, little attention is paid to the paviors' method of laying the setts. The result of this lack of inspection is that many streets and tracks suffer from small hills and hollows, which are particularly noticeable and objectionable during wet weather. Paving should be carefully executed in the following manner:

The paving bed having been spread evenly over the surface of the foundation, the pavior takes a sett in his left hand, and with a broad-ended paving hammer he shapes the bedding to receive the stone, which is gently placed in position. If the sett is not low enough it should on no account be struck with the hammer, as is frequently done, but it should be removed and the bedding lowered and then placed back. The pavior, by pressing on the sett with his hammer, is able to detect at once whether it will rock or not. If it rocks or is too low, it must be taken up and additional bedding must be carefully spread before the sett is replaced; on no account must the paving hammer be

used for beating extra bedding beneath the sett without removing the same, although this is of common occurrence amongst inferior paviors. When setts are hammered down, or where extra material is packed tightly beneath them whilst they are in position, they will not be depressed to the same extent as the adjoining setts during the ramming operation, with the result that there will be either a considerable number of high setts forming hollows with those next to them, or if these are detected much trouble is experienced in lowering the high setts during the ramming operation. The ramming of setts requires a skilled workman's patient attention. All setts should be rammed down

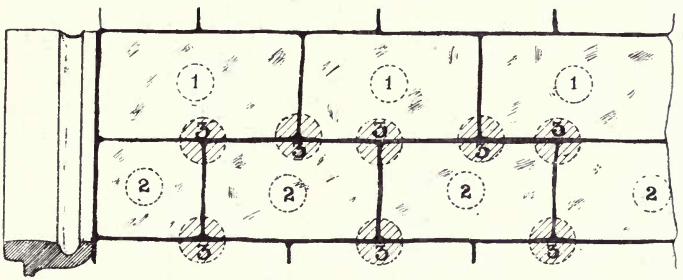



Fig. 116.—Procedure in Ramming Two Courses of Setts.

the same amount. It is the pavior's duty to bed the setts evenly, and the rammerman's duty to ram them uniformly into the bedding. It is not part of the rammerman's job to ram down high setts. If the setts have been properly paved there will be no high setts after being rammed. The paving should be rammed sett by sett and course by course in the following manner : Commencing with the sett next to the rail, the rammerman rams it down hard by striking it fair in the centre, giving each sett in the course the same treatment as he makes his way across the track. The next course is treated in a similar manner, and finally the setts are rammed across each joint, as shown in Fig. 116, so as to engage three setts, and to ensure the courses

being in the same level. It will be seen that each set is thus rammed at each corner and in the centre. All setts which sink too low under the ramming should be removed and additional bedding should be added. A story is narrated about a trustworthy but not very intelligent navvy who was being tried as a rammerman, to the effect that in ramming the paving he sent one sett very much below the others; it did not occur to him that the sett could be raised, but in order to carry out his instructions to the letter he rammed down all the adjacent setts to the same level.

Care should be taken to secure an even depth of bedding beneath each sett, and as setts vary slightly in depth they should be gauged and all setts of the same depth should be paved together.

The setts along the side of the rail should be paved to the same level as the rail. There is nothing to be gained by paving them above the level on the assumption that they will wear down more rapidly than the rails. When they are paved above the rail level the arrises are soon broken off and the sett is ground down to the level of the rail in a very short time, causing the formation of ruts alongside the rail and frequently shattering the setts. In conclusion, it may be repeated that the best results will be obtained from paving a track with broad, flat-topped, well-dressed, tight-jointed setts with sharp arrises, made from granite with hard wearing properties.

# CHAPTER XIII.

## RECONSTRUCTION.

The question of track reconstruction has to be faced sooner or later on all systems, and it is intended in this chapter to review the most economical methods of executing the same without entirely suspending either the tramway service or the vehicular traffic. It is somewhat difficult to lay down definite rules as to the exact period when a track is ready for renewal; so much depends upon the general condition of the track, the speed and frequency of the service, and other local considerations. In valuation cases and the like, too much importance is placed upon the relationship between the depth of the groove and the life of the track. In actual practice the depth of the groove plays but a minor part in the life of the track and can in no case be taken as a standard for the determination of either the remaining life or the residual value of the track. As the writer has indicated in the chapters dealing with rail wear, the wear of modern rails has not proved at all satisfactory and the weight of traffic carried affords little or no information on this point. Many tracks are worn out before the wheel flanges are anywhere near the bottom of the rail groove, whilst it has been possible to operate other tracks for several years after the floor of the groove has been reached. On two tracks the writer has charge of, it was possible to grind $\frac{1}{8}$ inch of metal off the floor of the groove and so facilitate the progress of the wheels after the allotted amount of metal had been worn off the rail tread.

Again, the concrete foundations are frequently

discovered to be fractured from one cause or another, and where such defects exist to any extent the expenditure upon maintenance is generally out of all proportion to the residual life represented by the depth of the groove.

The depth of the groove will vary considerably in the same rail and different tracks will give different results. As previously stated, too much importance is attached to the depth of the groove; this is more apparent when it is considered that the value of the rail represents only about 20 per cent. of the cost of reconstruction, from which it will also be evident that extensive repairs to the foundations, paving, joints, etc., are a sheer waste of money merely to prolong the life of the rail a few years, at the end of which the same expenditure coupled with the renewal of the rail has to be incurred.

The cost of track reconstruction is a variable quantity and will depend upon the gauge and form of construction, the actual condition of the existing foundations and paving, and also upon the distance from the centre of the system, the width of the streets, and the density of both the car service and the ordinary traffic. It is obvious that if much of the work has to be executed during the night, or if the provision of a thoroughfare, for the whole or part of the street and car traffic, impedes the progress of the work, that the cost of reconstruction will be proportionately high. It is, therefore, impossible to give any definite figures in regard to the cost of this work; which varies between 30 shillings and 60 shillings per yard of single track exclusive of special work. Provided the foundations are sound and the works may be executed during the daytime without much interruption, a track may be relaid in the most up-to-date manner, with welded joints, frequent anchors, high quality steel rails and

redressed granite setts for little more than 40 shillings per yard of single track exclusive of special work.

There are many ways of executing the renewal of the track, the choice of which will depend entirely upon circumstances. These are briefly as follows :— (1) By the use of a temporary track laid alongside the main track, as shown in Fig. 117 ; (2) By converting a double line into a single line for a short distance,

Fig. 117.—A Temporary Track.

through the insertion of temporary loop-ends ; or (3) By relaying short lengths of track during the night and paving up the same either at night or during the following day.

Probably the most economical and efficient method is number (2) with temporary loop-ends. These turn-out ends may be either of old points and crossings laid in the track, or they may consist of new purposely made materials laid upon the surface of the paving as

shown in Fig. 117. It is necessary that the two turnouts should be right and left hand respectively and when the mate track is relaid the turnouts will require to be moved from one end to another. Of course there are many instances where it is impossible to interfere with the car service to such an extent as this and in such cases it is better to lay a length of temporary track down; this, of course, causes the least delay to the car service; but as it occupies more space it does

Fig. 118.—Temporary Track and Cross-over. (1) On to reconstructed "outgoing" track. (2) "Incoming" track under reconstruction.

not afford so much room for the reconstruction works and the ordinary traffic. There are several types of special tracks in use; but without doubt the most satisfactory results are obtained from those having a girder type of rail. Flat rails are not suitable for well cambered streets, as the outer rail has frequently to be raised considerably, thus necessitating the use of either sleepers or numerous well secured packing pieces. The writer has not found any disadvantage from the use of a girder temporary track rail and there is far less

liability to a derailment with its use. Fig. 118 shows the details of the temporary track used in Leeds.

A very economical and satisfactory temporary track may be formed by "throwing out" the track to be reconstructed; this is done after the removal of the paving and the releasing of anchor bolts and other fastenings, by freeing both ends of a length of the track to be relaid and levering the same to one side of the road so as to form a temporary track, the ends being coupled up, by means of curved closers. The third method of reconstruction, *i.e.*, by nightwork, is considered by many people to be a very unsatisfactory way of executing the work, and that work done in this manner is generally scamped. This may be the case on systems where the permanent way works suffer either from the inexperience of the staff or from being understaffed; but where the operations can be properly supervised there is no more satisfactory method of carrying out the work; and in addition there is this undoubted benefit derived from nightwork, that as the works are executed at an uniform temperature, there are no deleterious effects from expansion and contraction of the rails, which are, as the writer has instanced in these pages on several occasions, responsible for so much of the trouble experienced from loose rails and the like. For this reason it is advisable that the works should be paved up as the job proceeds and not left until the following day. On account of the expense it is only advisable to execute works of this description during the night where it is not possible to lay a temporary track, as in the busy parts of a city. Where the concrete foundations are fractured, the new concrete will have to be inserted, in a case like the above, before the new rails are laid. The method of doing this was illustrated in the chapter on concrete, and consists of the interposition

of short lengths of small channel iron beneath the track rails, thereby raising them above the new concrete. These supports are kept in position for several days, until the concrete has hardened, and the trench is kept open during this time. Considerable saving is effected on both new works and the reconstruction and repair of old tracks, by the use of the electric hopper wagons illustrated in Fig. 119. These wagons, which have a

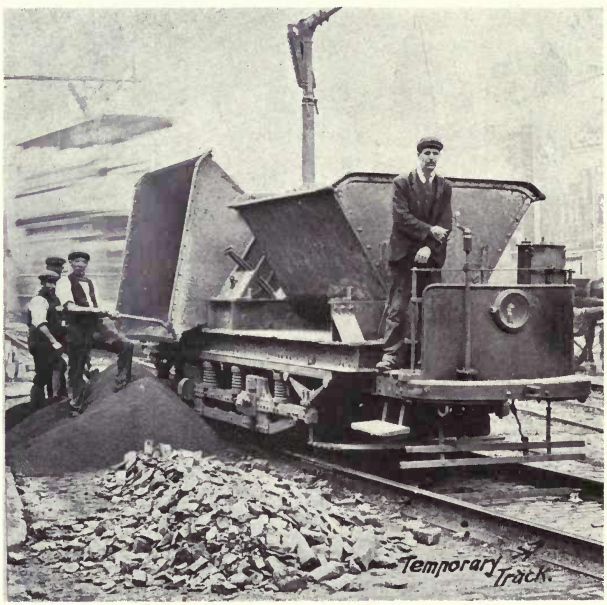



Fig. 119.—An Electric Hopper Wagon, as used on the Leeds Tramways.

capacity of ten tons, are fitted with standard equipments and do not inconvenience the ordinary car service. The hoppers are easily removed and the vehicle converted into a flat wagon. In addition to a great saving in the cost of "horse hire," materials may be transferred to and from the central depot in a fraction of the time occupied by horse haulage. On reconstruction works, a short siding is provided for these wagons, at one end of the temporary track as shown in Figs. 117 and 118.

# CHAPTER XIV.

SURFACE DRAINAGE—RAIL CLEANING—RAIL GRINDING.

In order to obtain the most satisfactory results in operating tramway points it is necessary that all movable points should be drained; it is further necessary that they should be examined, cleaned and oiled daily. Trapped drain boxes should not be used, as they soon "choke," but it is recommended that trapped catch pits, as shown in Fig. 120, should be interposed between the points or drain box and the sewer.

Drain boxes and trapped sump pits should be placed in the track at all changes of gradient, but it is essential that they should be attended to daily if they are to be of service when required. Fig. 120 illustrates suitable types of drain boxes, traps and the connections; the boxes are attached to the rail webs, as shown, and a long slot hole is formed in the groove in order to drain off the water; the slot and the holes in the web may be readily executed by means of the oxy-acetylene blow-pipe.

## Rail Cleaning.

The writer is of the opinion that much benefit may be derived from the careful cleaning of the rail grooves at frequent intervals, though many systems do not trouble to attend to this matter; it is obvious that there must be increased resistance to traction and excessive current consumption where the grooves are allowed to become full of tightly packed road dust. For this purpose the writer advises the use of rail scrapers similar to that shown in Fig. 121; these may be attached to the side frames of a stores car, and the

frequent and regular use of the same will prevent the hardening of the grit in the grooves. The chief objection to the use of such appliances as these is the dust which is created when the car is travelling quickly on dry days. In the more important thoroughfares it is better that such work should be done by manual labour. A long light bar inserted in the groove and pushed steadily along with a swinging motion in front of the

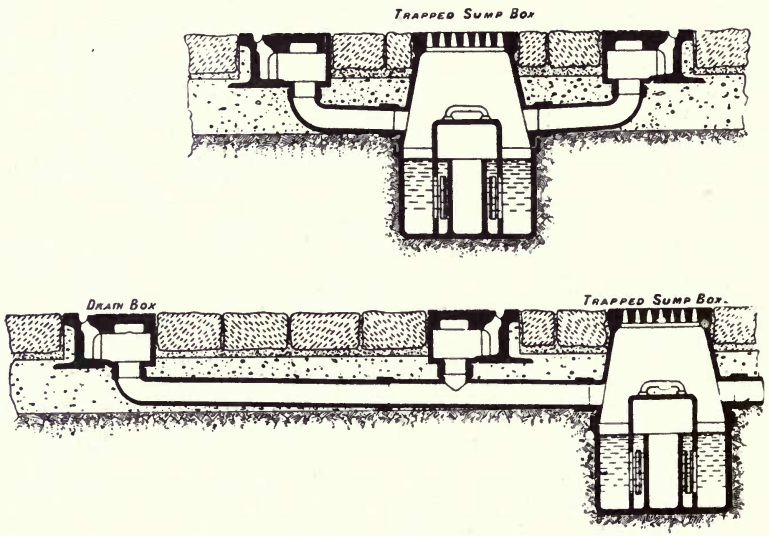



Fig. 120.—Trapped Drain Boxes.

operator will quickly move the dirt out of the groove. The detritus must afterwards be swept up.

## Rail Grinding.

It is essential that every tramway, of any size, should possess portable electrically driven grinding machinery for the purpose of truing up special work and the removal of corrugations. The life of worn points, crossings and rail joints may be considerably increased and the path of the cars rendered easier by the judicious grinding of worn paths.

On the majority of British tramways it is necessary

that such machinery should be regularly employed on the removal of corrugations; otherwise much damage is done to both the rails and the rolling stock if the corrugations are permitted to become too pronounced. It is true that the effective life of the rail is decreased to some extent by this treatment, but, on the other hand, if corrugations are left untended they generally reach a stage where battering commences, and from this point the deterioration is rapid and remedial measures are impossible. In several instances, where corrugations have been removed, the writer has had the floor of the rail groove ground down to a like extent, with the result that the full life of the rail has been obtained. The grinding of corrugations and long lengths of battered rail requires to be very carefully carried out, and the machinery should possess both speed and accuracy, otherwise the cost will be high and considerable damage may be done to the rails.

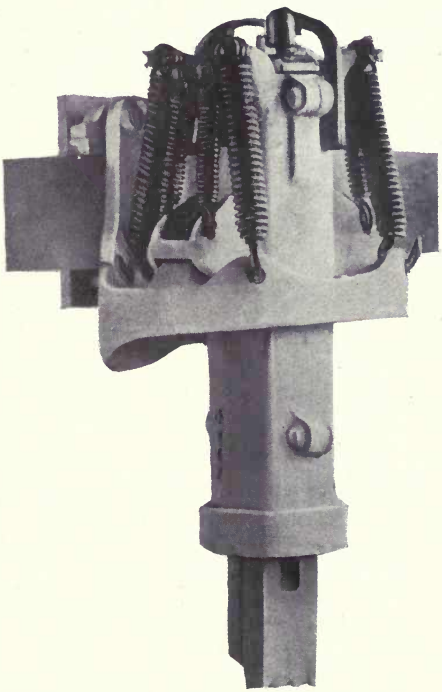


Fig. 121.—"Q" Fel Rail Scraper.

Corrugations have been kept down on the Leeds tracks for the last nine years by means of the grinder shown in Fig. 122. This machine is equipped with two 20 inch corundum wheels, revolving at the rate of 5,200 feet per minute, and two "screw down" corundum slipper blocks.

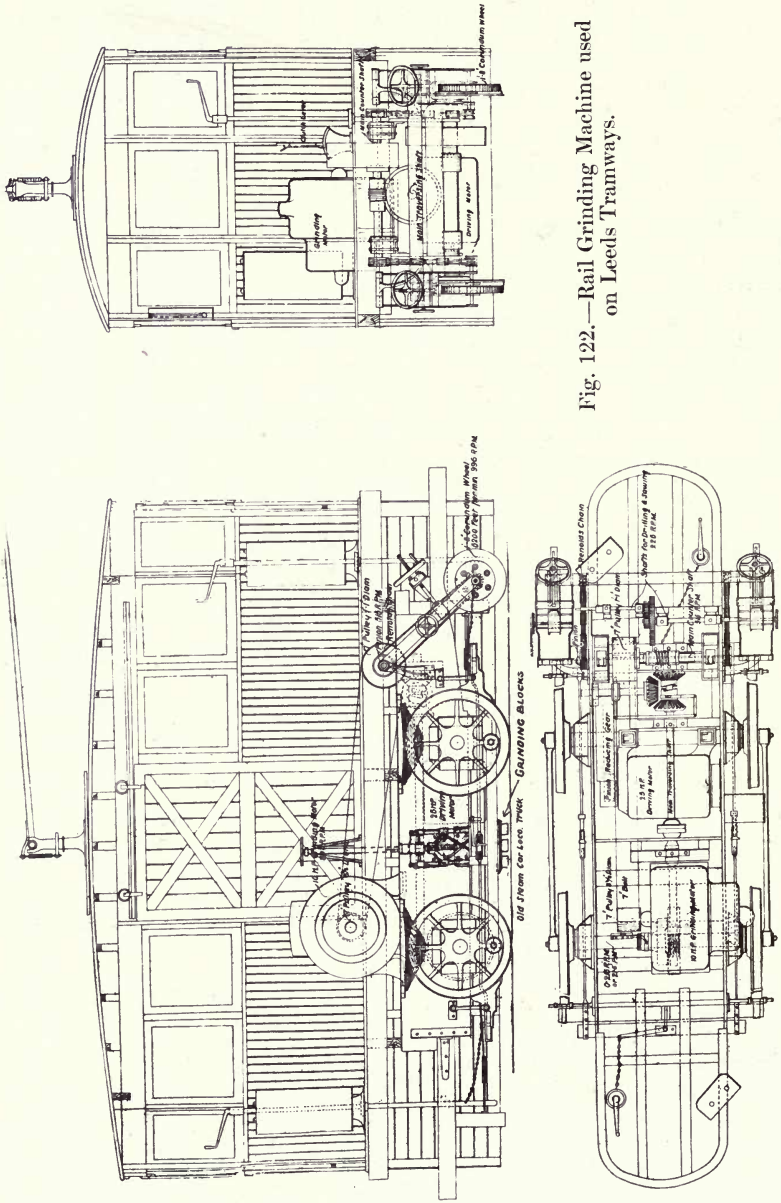



Fig. 122.—Rail Grinding Machine used on Leeds Tramways.

The design of this machine contains several faults common to nearly all rail grinding machines; in the first place, owing to its bulk it can only be used at night, and secondly, in traversing it regularly happens that one or more wheels are resting upon the summits

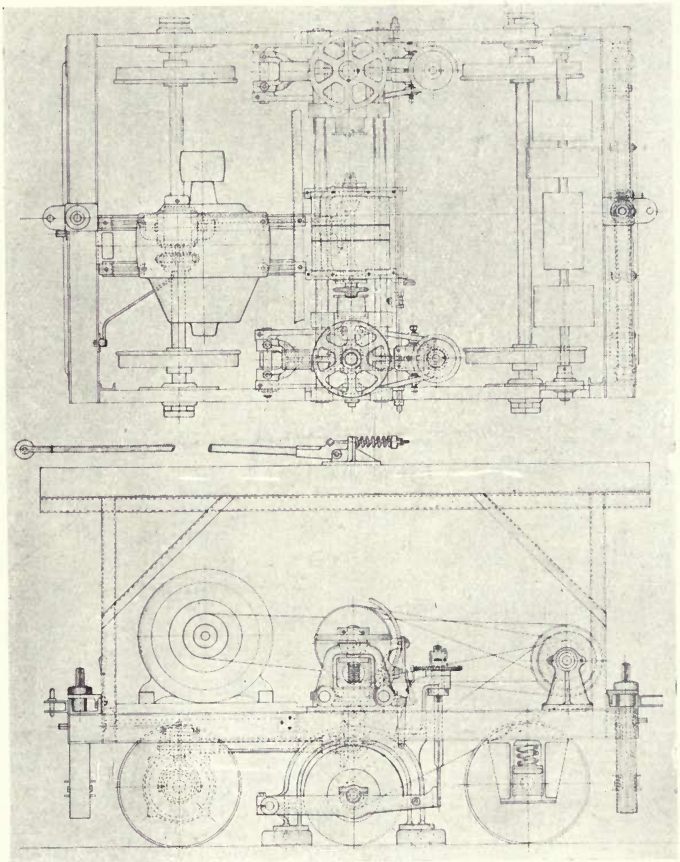


Fig. 123.—Rail Grinding Machine.

of the corrugations, whilst the other wheels are in the hollows, and *vice versa*, with the result that accurate grinding and surfacing are impossible, and unless great care is exercised irreparable damage may be done.

In order to obtain accurate results it is necessary that the grinding wheels should be controlled by guides

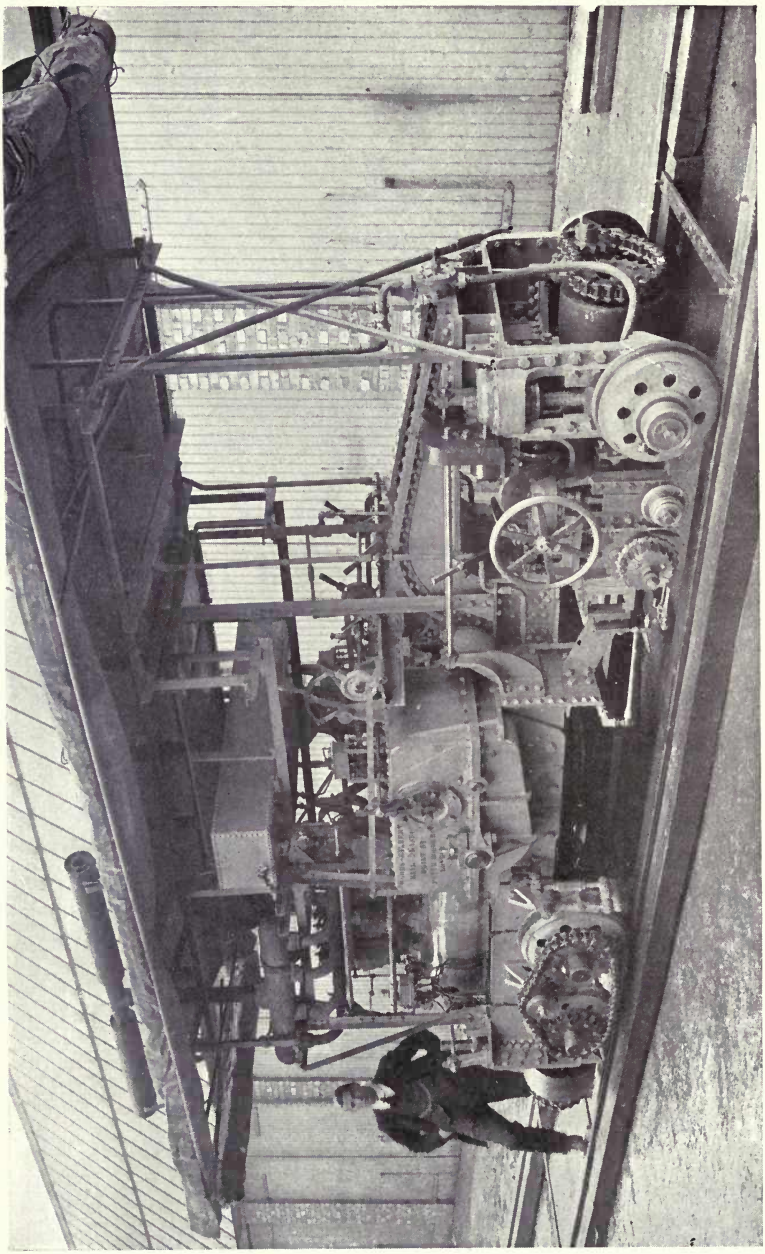


Fig. 124.—Woods-Gilbert Rail Planing Machine for Re-surfacing Worn Rails.

which are independent of the body of the machine, as shown in Fig. 123, which illustrates a machine designed by Mr. E. Rhodes, and manufactured by Messrs. Thos. Green & Son, Ltd., Leeds. This machine has a positive action and is guided by means of a swinging frame equipped with roller slides which travel upon the rail, thus determining the correct angle for the grinding wheel traverse ; it has micrometer adjustments, together with side tracking wheels which enable it to be used whilst the cars are in service.

Probably the most noteworthy effort to tackle the problem of rail surfacing is that made by the Woods-Gilbert Rail Planer Company, whose rail planing machine is shown in Fig. 124. The remodelling of the rails by this process, comprises the deepening of the groove, the cutting down of the guard lip, and the removal of the dish at joints and of corrugations. The work is performed by a single machine which combines the work of a cutting, surfacing, and grinding machine. The function of the machine is to deepen the groove and at the same time to cut down the protecting guard lip, thus giving an increased life to the rail beyond the ordinary period, and also minimising accidents to vehicles from the projecting lip. The machine is substantially constructed and of high-class material and workmanship. It is so accurately balanced and adjusted that it cuts out the rail groove to within $\frac{1}{64}$th of an inch of the standard depth under all conditions of track. This machine, of which a view is given in the accompanying illustration, weighs up to 15 tons, and it cuts the groove and guard lip of both rails on the track at a speed of about 9,000 feet per month when at regular work. The machine has suitable under-gearing to enable it to be run along tracks at any desired speed when not engaged in remodelling work. It can be quickly removed from

the track by a lateral movement and housed at depots along the routes. The work is carried out at night after the cars have stopped running, and the tracks are left clear in the morning.

The mileage which has been remodelled up to the present is over 75 miles of single track. This includes work carried out on the Melbourne, the Sydney, and the Brisbane tramways in Australia, together with the remodelling of the rails on the Oldham, Ashton, and Hyde tramways, in England. The company have also carried out contracts for the Cardiff Corporation and the Isle of Thanet Electric Tramways and Lighting Company.

The writer has witnessed the operation of the rail planing machine on the Oldham, Ashton, and Hyde tramway and was favourably impressed with the manner in which it performed the work of deepening the grooves and lowering the check. The work was rapidly executed and with great accuracy.

# CHAPTER XV.

## SPECIAL TRACKWORK.

SPECIAL trackwork is the term which is now generally, but somewhat loosely, applied to describe tramway points, crossings, junctions and lay-outs of all descriptions. Taking British tramways as a whole, it will be found that there is such a lack of uniformity in design, materials, and the lay-out of the various units which come under the heading of special work, that very considerable expense is incurred both in regard to first cost and in stocking spare castings, tongues, and accessories. At the present time the majority of tramway systems have their own particular types of points and crossings, and a standardisation of design in this direction would lead to an immediate decrease in the cost of production. The purchaser has to pay for the preparation of patterns, and the manufacturers are put to very considerable inconvenience in regard to the storage, repair, and classification of these special patterns, many of which after being kept for some years are no longer required owing to further changes in the design. Tramway managers and engineers are not altogether to blame for this state of affairs, because the manufacturers of special work are continually changing the design of their productions in some way or another. That many of these alterations are in the direction of progress may not be denied ; but a great number have no practical value, and are chiefly introduced in order to give a distinctive character to a particular manufacturer's wares. Points and crossings supplied by the different manufacturers to specified radii and dimensions differ to such an

extent in regard to design that it is not possible to make up a pair of points from single points to the same specification supplied by different manufacturers, or even to interchange tongues of the same general dimensions. Again, in regard to springs, tongues, and other fittings, each firm has its own particular design, with the result that many different types of spare parts have to be kept in stock. One very excellent result of standardisation of special trackwork would be the interchangeability of entire castings, fittings, and spare parts and the reduction in the number of duplicate spare parts it is necessary to keep in stock. According to the replies to the list of queries recently issued by the Municipal Tramways Association, points vary in radii between 30 ft. and 350 ft. for lateral turn-outs, whilst one system has double-curved points for equilateral loops of 450 ft. and 1,000 ft. radius. Such a range of curvature is quite unnecessary, and the fact that many systems have a dozen or more types of points is due more to caprice than to any local conditions. There are, of course, some exceptional cases where an odd point or crossing may require special curvature or to be compounded with some other casting, but such cases are exceptional, and in Leeds, where there are some two hundred junctions of one kind and another, there are only about three instances, excluding depot sidings, where specially designed points are required on the main track. The table on page 194 gives particulars of the five different types of points which will meet the requirements of any up-to-date track. It will be noticed that although there are five distinct sets of points there are only three different designs, Figs. 125, 126, 127, viz.: The 200 ft. double-curved points for equilateral loops, the 150 ft. radius points for lateral turn-outs, and the 75 ft. radius points for lateral turn-outs of sharp curvature, the other two varieties given in the table being for the

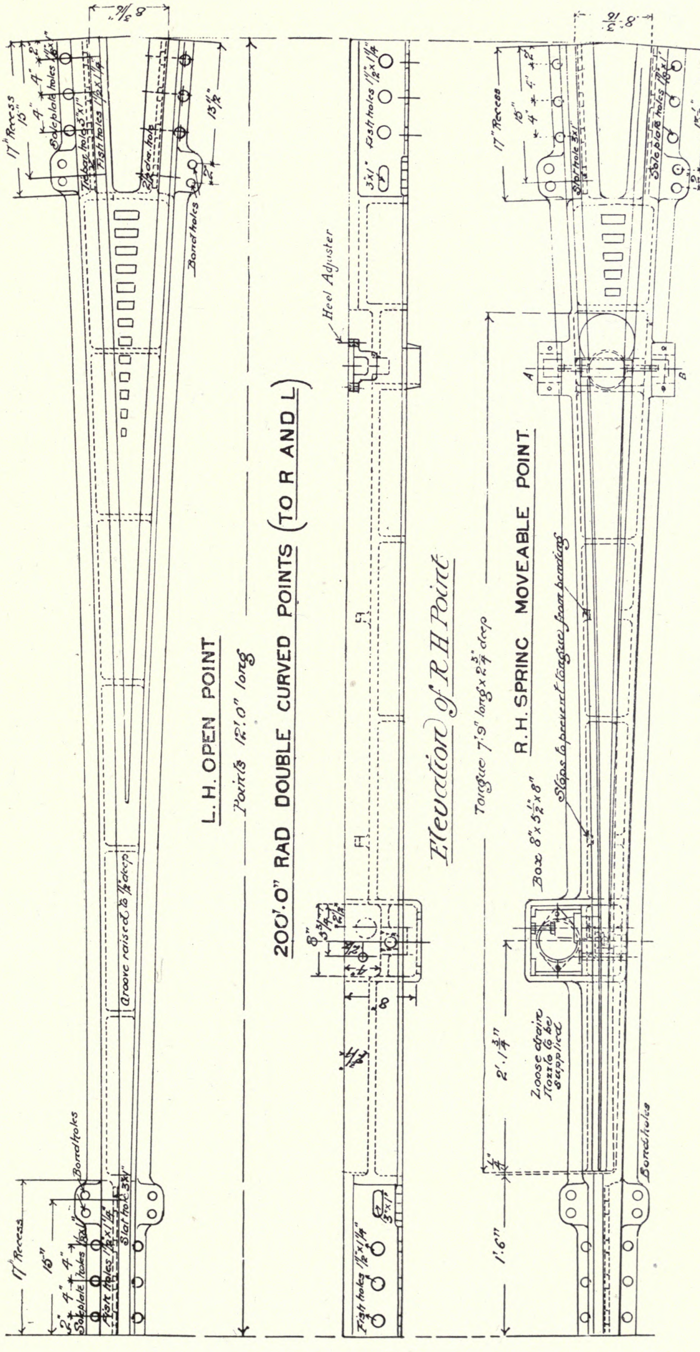



Fig. 125.—Showing Detail of Points (Design No. 1—Table, p. 194).

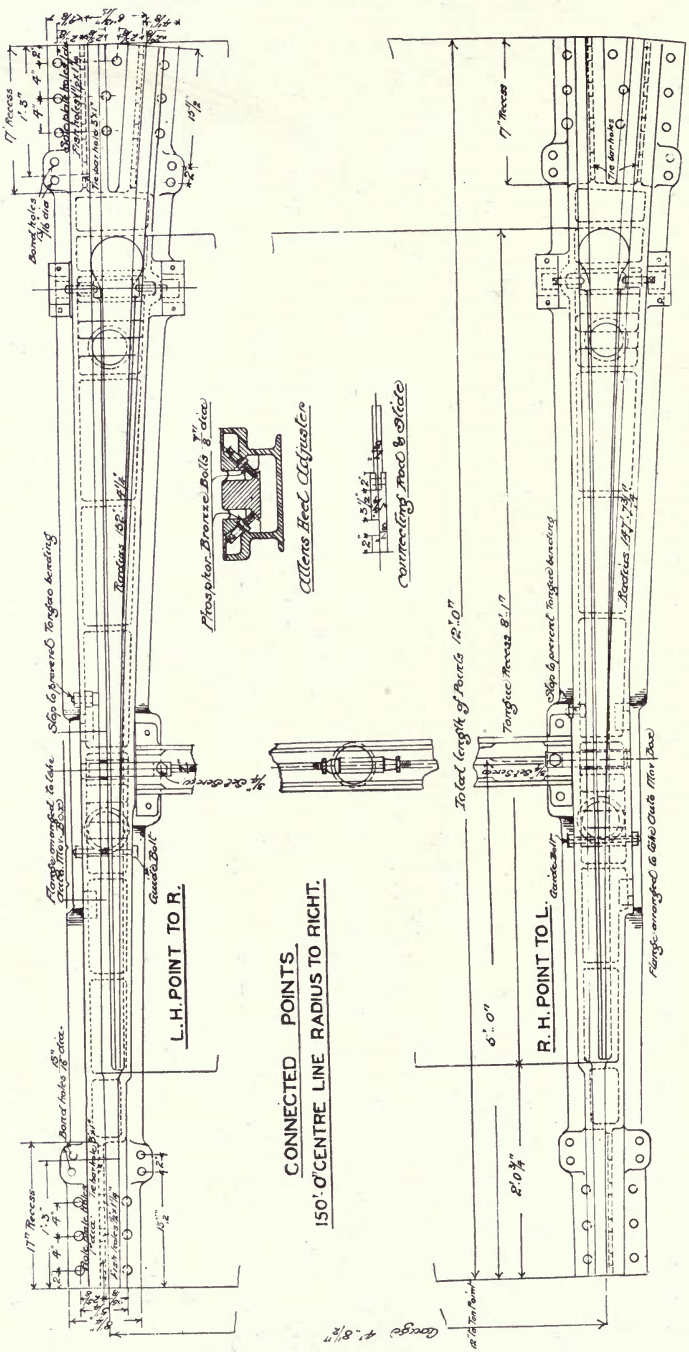



Fig. 126.—Showing Detail of Points (Design No. 2—Table, p. 194).

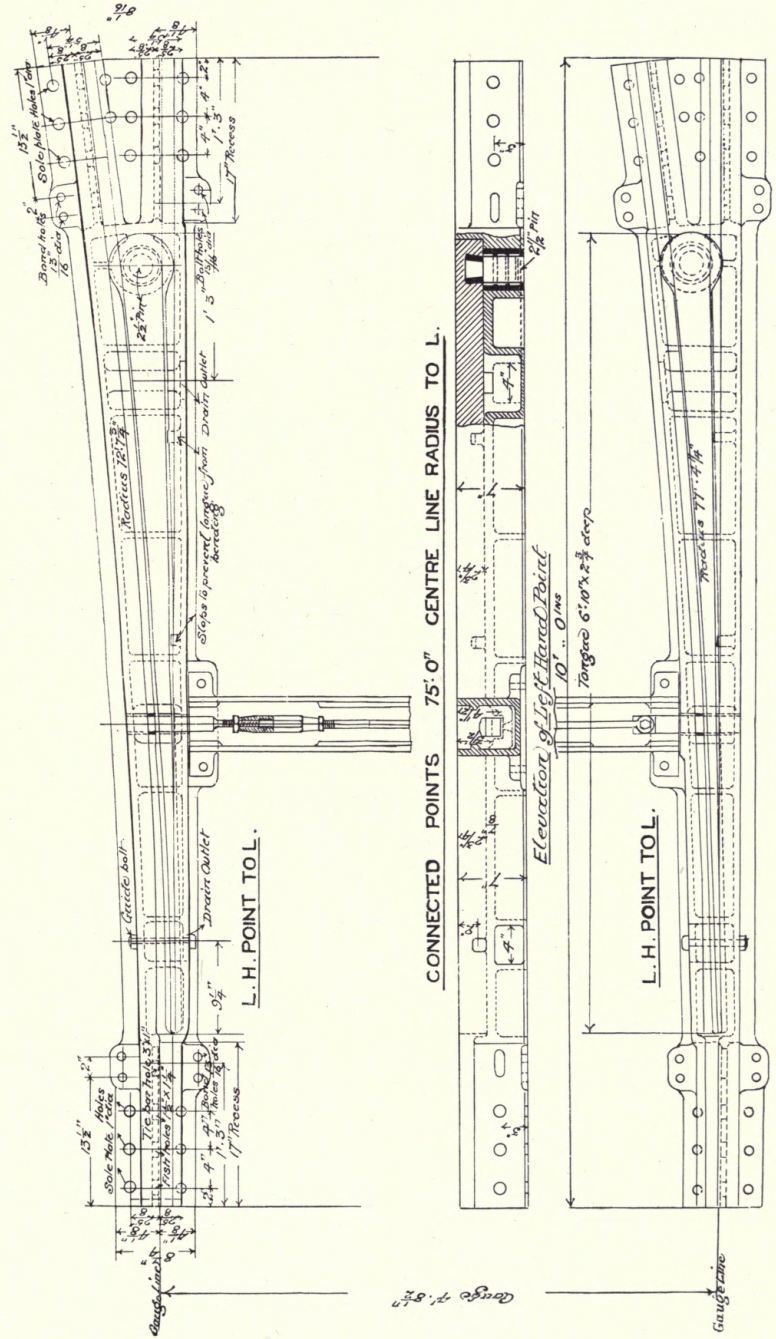



Fig. 127.—Showing Detail of Points (Design No. 3—Table, p. 194).

left hand turn-outs of 150 ft. radius and 75 ft. radius respectively.

TABLE OF STANDARD POINTS (PAIRS).

| Location. | Radius. | Turn-out. | Length of Tongue. | Overall Length. | Design. | Fittings. |
|---|---|---|---|---|---|---|
| | ft. in. | | ft. in. | ft. in. | | |
| Equilateral loop ends (Fig. 125) | 200 0 | Right and Left | 7 6 | 12 0 | No. 1 | Standardised |
| Right hand turn-outs (Fig. 126) | 150 0 | Right | 8 0 | 12 0 | No. 2 | Do. |
| Left hand turn-outs and cross-overs (Fig. 126) | 150 0 | Left | 8 0 | 12 0 | No. 2 | Do. |
| Right hand turn-outs (sharp curves) (Fig. 127) | 75 0 | Right | 8 0 | 10 0 | No. 3 | Do. |
| Left hand turn-outs (sharp curves) (Fig. 127) | 75 0 | Left | 8 0 | 10 0 | No. 3 | Do. |

For all the above-mentioned points the fittings such as drain boxes, heel adjusters, springs, and other parts and mechanism may be standardised and interchanged. The mates for these points may be either connected movables or open points, according to the requirements of the particular system. In regard to straight crossings for cross-overs and loop-ends it is not necessary to use more than one type, and for the 12 ft. points in the above table a 1 in 5 straight crossing (Fig. 128) will be found to give a very easy entrance to both equilateral and lateral turn-outs. The writer has tried points of larger radii and more acute straight crossings for loop-ends, and although, with reasonable speeds, a much easier entrance may be obtained, the results have not been anything like so satisfactory as with the designs Nos. 1 and 2 in the table with the 1 in 5 crossing. The reason for this is simple and as follows: With the larger radius points the motormen run through the turn-outs without reducing the speed of the car, with the result that the digression of the car from the

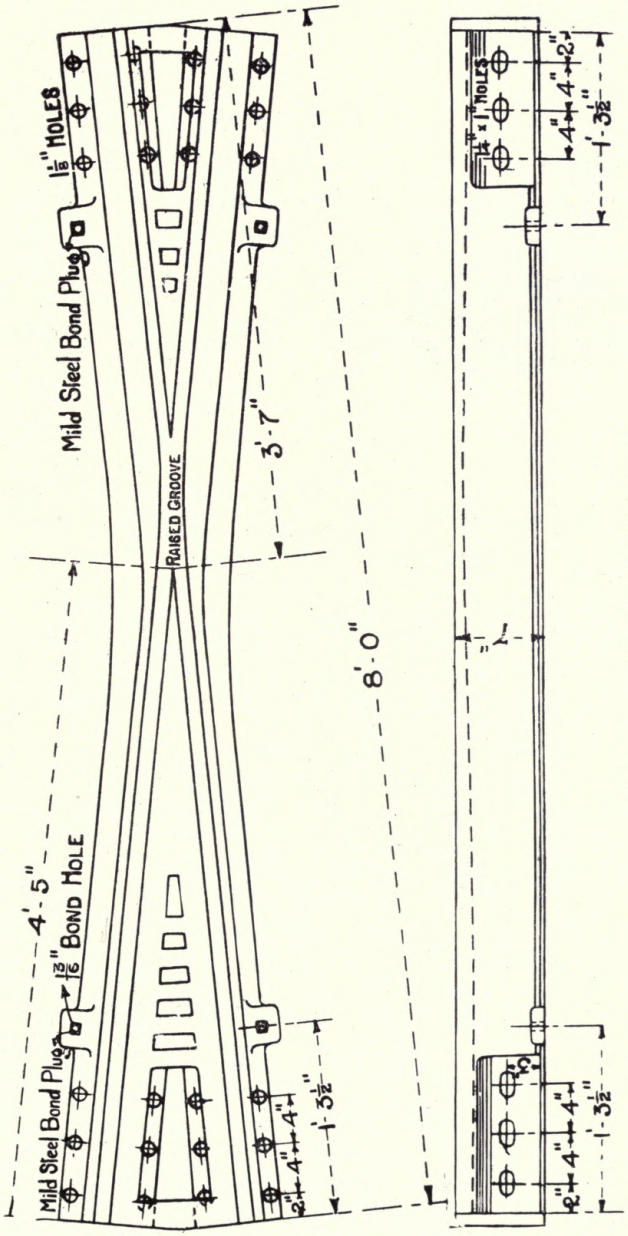



Fig. 128.—1 in 5 Straight Crossing.

straight is accompanied by a side swing which neutralises the effect of the easy entrance, and causes more discomfort to the passengers than points of less radius with the 1 in 5 crossing. This crossing will also be found to be quite satisfactory for cross-overs, but for this purpose the writer recommends that two designs should be used, viz., the ordinary 8 ft. straight crossing

Fig. 129.—Solid Manganese Steel, Ordinary 8 ft. Crossing.

Fig. 130.—Iron-bound Crossing, 8 ft. long with Manganese Steel Renewable Centre.

Fig. 131.—Solid Manganese Steel, Unbroken Main Line Crossing (1 in 5).

shown in Figs. 129 and 130, and the unbroken main line types shown in Figs. 131 and 132. The former to be used where the cross-over is in frequent use, and the latter on emergency cross-overs, where the advantage of the continuous rail to the main track service will be obvious (see Fig. 133). A very considerable difference of opinion exists as to the composition and design of the points and crossings. Many systems prefer solid manganese steel castings, some few prefer

manganese steel with renewable inserts, whilst some important systems prefer toughened cast steel with manganese steel inserts at the places which are subjected to the greatest wear. The crossings are also to be obtained in another variety of manufacture, viz., the

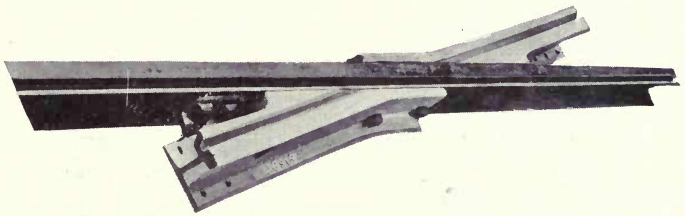


Fig. 132.—Crossing with Unbroken Main Line.

iron-bound type shown in Fig. 130. In this type the legs of the crossing are of rolled steel rail, the body of cast iron, and in the intersection of the two grooves a renewable plate of manganese steel is inserted. There

Fig. 133.—Unbroken Main Line Crossing in Track.

can be no doubt that the local service conditions, the design and upkeep of the rolling stock and tyres have a very decided effect on the wear of the special trackwork, and an examination of the behaviour of the above-mentioned types on different systems proves clearly

that materials and designs which have been found satisfactory on one system will not necessarily wear well on another system. For example, points and crossings with renewable inserts give good results in, say, Manchester and Glasgow, and similar materials fail in Leeds and other places. The writer has used crossings of both the iron-bound type and of toughened cast steel in Leeds, each with renewable manganese steel inserts.

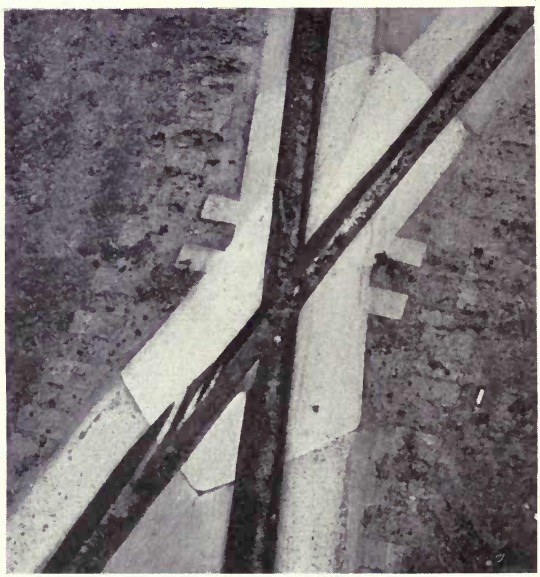


Fig. 134.—Showing Lateral Wear on Legs of Curved Crossing with Manganese Steel Insert.

Fig. 134 is a photograph showing a crossing of this type in position in the track after about ten years' continuous service. As will be seen in the illustration referred to, the lateral wear on the legs of the crossing is so pronounced as to prevent the replacement of the renewable centre plate. The renewable plate itself resists the lateral wear, except at the point where it joins up to the legs of the crossing, where, owing to the excessive wear on the legs, it becomes bevelled, as

shown. Such are the results of actual wear in Leeds, where it is found that owing to the different rates of lateral wear on the different materials forming the crossings, it is not possible to renew the centre plates on curved crossings. This irregular lateral wear depends to a certain extent upon the design of the rolling stock, the attention paid to the condition of the wheels and wheel gauge ; and several important systems, including Manchester, report that they are regularly effecting renewals of this kind.

In regard to points, it is the writer's experience that the renewable plates which are usually fitted in points of this type are far too short for the purpose. Fig. 135 shows a point in the road fitted with a renewable plate at the toe of the tongue. This point has been subjected to a very severe weight of traffic on one side, but only a light service has been borne by the other side. It is evident that such a plate could not be replaced satisfactorily without special allowance for wear ; notwithstanding this there are many thousands of points and crossings of this type in use in this country. The writer is of the opinion that the most satisfactory type of renewable plate for points is the one shown

Fig. 135.—Manganese Steel Insert at Toe of Point.

in Fig. 136, which is the "tadpole" switch, supplied by the Lorain Steel Company. The design of this point is novel and contains many new and useful features, chief of which is the increased bearing provided for the full length of the tongue. At the head of the tongue, alone, the bearing equals 60 square inches. In Leeds, the most satisfactory results have been obtained from the use of solid manganese steel points and crossings, and in all cases the extra cost of this material has been more than covered by the benefits derived from the regular wear and the increased life. It is considered by some engineers that it is irregular in quality, and that it is susceptible to internal sponginess to such an extent that it is like buying "a pig in a poke." Such has not been the writer's experience with this quality of steel, and from a close examination of many hundreds of castings. In Leeds, the life of no manganese steel casting has been affected by defects of this kind, and where at rare intervals slight signs of sponginess have been detected, either prior to being laid in the track or after being in service for some time, the manufacturers have willingly offered to replace the castings free of charge should the presence of the blow holes have any effect on the wear. Manganese steel points and crossings wear regularly, except at the intersections, and as the steel possesses great toughness and durability rather than great hardness, it is, in the writer's opinion, the most suitable for all classes of special trackwork. Manganese steel has another decided advantage, in that it takes a perfectly smooth, silver-like polish, which is a great assistance to the car wheels in negotiating curves, points and crossings.

In regard to the design of points, there can be no question that the connected movable points shown in Figs. 126 and 127 are the most perfect in design and

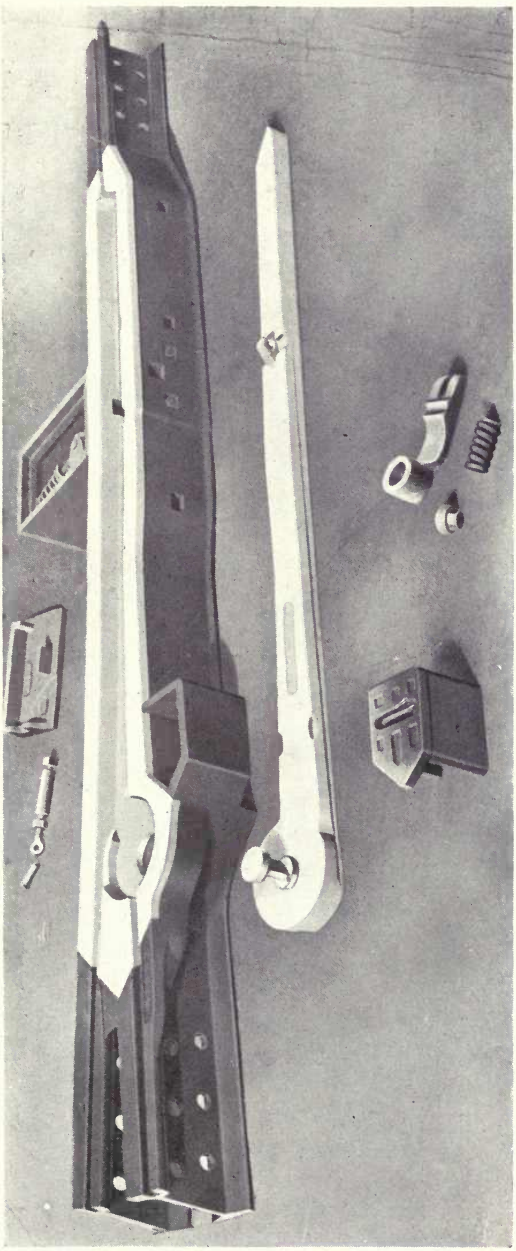
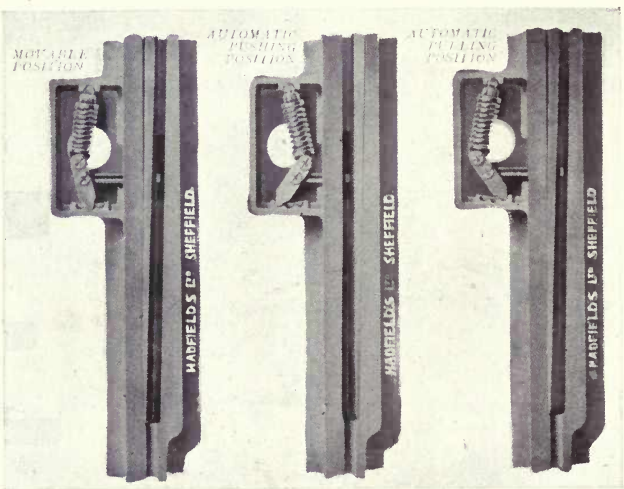


Fig. 136.—Lorain Tadpole Switch.

action when properly attended to. With connected movable points of this type much more care has to be taken in regard to cleaning, oiling, and the drainage of the points. Unless they are kept quite free from dirt and sand they will not work satisfactorily. The presence of brake sand and detritus in the tongue recesses prevents the tongue from working freely in the recess, with the result that both the tongues and con-




Fg. 137.— 3-Way Mechanism for Movable Points.

necting rods become strained during the passage of the cars and finally become locked, causing blockages in the car service on account of the difficulty experienced in removing the strained parts, which are frequently buckled to such an extent as to render extrication a slow and tedious operation. To these disadvantages must be added the extra expense incurred in providing and maintaining the additional springs, tongues, and other fittings. This duplication of spare parts is a very serious item for consideration on a large system, entailing, as it does, a larger outlay and the employment of a considerable amount of extra labour for cleaning and

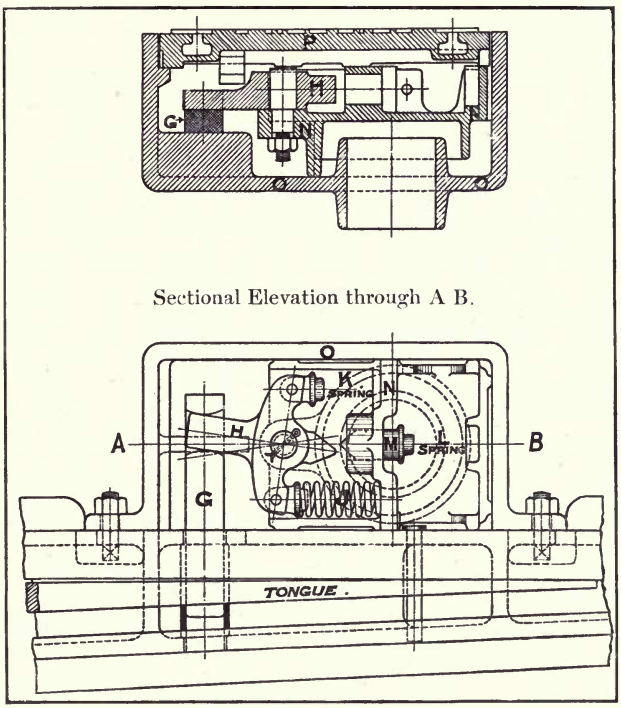



Fig. 138.—Allen's 3-Way Mechanism for Movable Points.

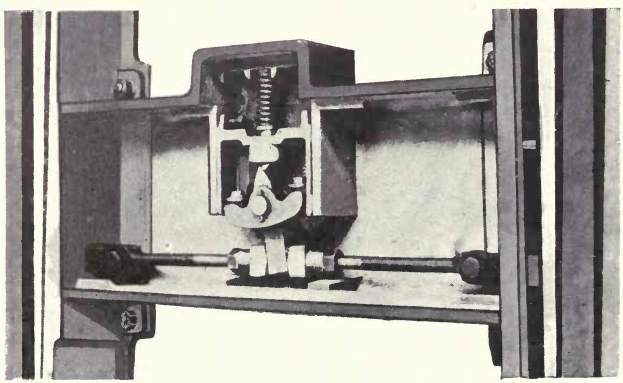


Fig. 139.—Allen's 3-Way Mechanism for Connected Movable Points.

maintenance. It is absolutely necessary for all movable points to be drained if they are to work satisfactorily, and provision should be made for draining them at both the toe and the heel of the tongue, so that the drainage may be effective whichever way the points may lie on a gradient.

In regard to point fittings and controllers, there are numberless types of efficient springs and other mechanism, and each maker has his own particular design. It does not appear to the writer that any one type possesses much advantage over another; as has been stated previously, the differences in design are chiefly to give a distinctive character to a particular manufacturer's wares. Figs. 137, 138, 139 show typical examples of the more prominent designs in point mechanism. Considerable trouble has always been experienced in regard to the steadying of the point tongues, particularly at the heel, where the greatest wear takes place through the heel getting out of alignment. With the idea of remedying this fault stout hardened steel pins were introduced into the heels of the tongues, as shown in Fig. 140, and these were a decided improvement on all existing devices for holding the tongue in position; but at the same time, with the increased speeds and heavier traffic, it must be admitted that they have failed to realise all that was expected of them. The heel of the tongue receives very severe treatment during the passage of the cars, and the hammering to which the tongue heel is subjected ultimately causes the heel pins to work loose and allow the tongue to work laterally. The failure of the heel pin has been so pronounced that the leading manufacturers of points have devised other means of securing and adjusting the tongue heels, particulars of which are given in Figs. 136, 141 and 142. In the heel adjusting devices illustrated particular attention is given to the grinding of both the

tongue recesses and the tongues, heel pins are entirely dispensed with, a true ground fit is obtained at considerable expense, and adjusting mechanism is provided. The writer has laid down a considerable number of points during the last twelve months equipped with the heel adjusters shown in Figs. 141 and 142, but it is too early to express any definite opinion on their merits. In spite of the failure of the heel pins, the writer is still of the opinion that they afford the most satisfactory means of securing the heel of the point tongue if they

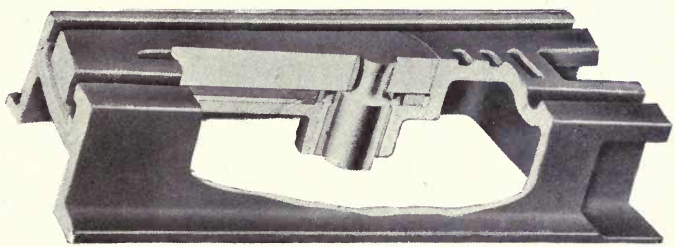


Fig. 140.—Section through Point Heel showing Tongue Heel Pin.

are suitably fitted. Heel pins may be said to have failed by reason of the defective application of the principle.

The heel pins which have failed were countersunk into the tongue and fitted into a bush, run round with spelter in the floor of the tongue recess. The failure was caused by the crushing and displacement of the spelter under the side pressure and hammering of the passing wheels, coupled with the loosening of the countersunk riveted head of the pin itself. A marked improvement in heel pins has recently been introduced, and in this case the makers, Messrs. Edgar Allen and Company, appear to have appreciated the earlier defects of the heel pin and have taken steps to avoid their recurrence. The heel pin is of hardened steel, and is attached to the manganese tongue by means of cast

iron which is run into a countersunk recess round the pin shank. The bush for the pin is cast in the tongue bed, and is afterwards bored out to make a perfect fit.

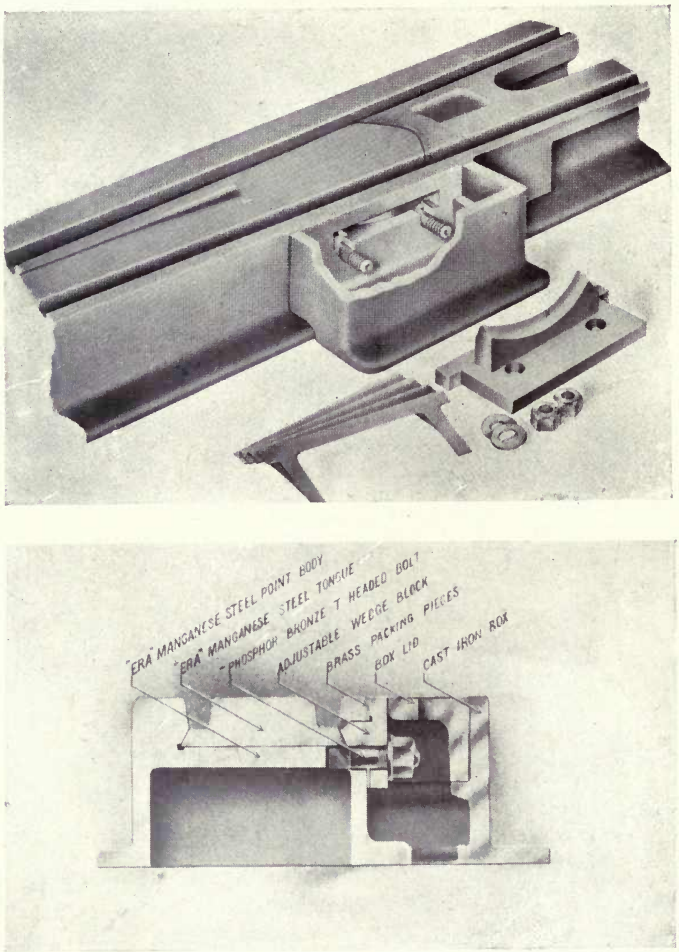



Fig. 141.—Hadfield's Patent Adjustable Pinless Point Tongue.

It would appear that this is a decided step in the right direction, and it is obvious that much better results will be obtained from the use of heel pins carefully fitted in this manner. The writer recommends the use of

both heel pins and adjusters on the same point. On account of the noise made by the return of automatic point tongues on single lines with loops it is frequently necessary to mitigate the nuisance caused, and the most satisfactory "silencer" which the writer has used is the one shown in Fig. 143, which was invented by Mr. W. A. McKnight, of Liverpool. This "silencer" consists of a cylinder, piston, and rod, with the usual actuating spring. The piston is perforated, but the holes, with the exception of a small one, are covered with a non-return valve; the cylinder is filled with oil which flows from end to end through the piston holes.

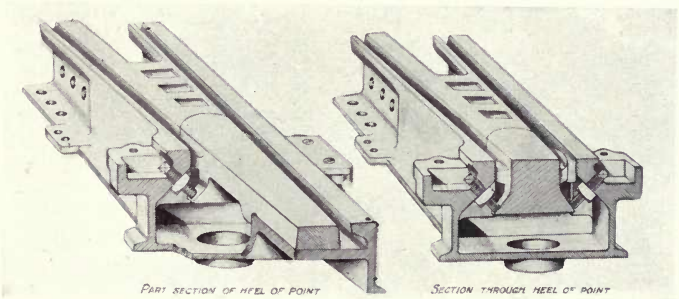



Fig. 142.—Allen's Patent Tongue Heel Adjuster.

All curves of 100 feet radius or less, which are subjected to a normal service of cars, should be fitted with a "check" or "guard" rail of wear-resisting steel, which may be readily detached and replaced. The use of such guard rails may be readily proved to increase the life of curves and junctions by at least 100 per cent.; in addition, the danger of derailment is reduced to a minimum.

The writer does not recommend the use of special rails, with wider grooves and thicker checks, such as are in use and in the list of the standard sections. No benefit is derived from the extra thickness of metal in the check; it wears away rapidly and allows the outer

rail head to wear in like manner, resulting in wide grooves which are a source of danger to the ordinary road traffic.

The writer considers it the best and most economical practice to remove the check of the ordinary section of rail used, and to replace it with one of the several suitable guard rails which are on the market.

The check may be removed, without difficulty, either

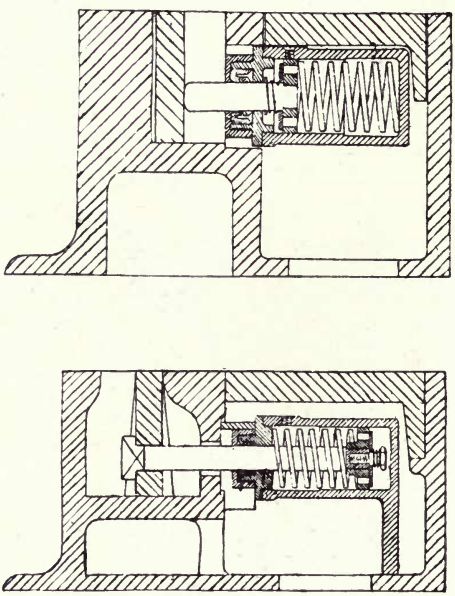


Fig. 143.—McKnight's Point Silencer.

by the oxy-acetylene process or with a hammer and cold sett. Care must be taken that the rail is bent to the required curvature before the check is removed or there will be a danger of it fracturing if the bending is attempted afterwards.

Figs. 144 and 145 show the guard rail designed by the writer for the Leeds tramways which has been extensively used at home and abroad.

It consists of a small "double" headed rail in Allen's rolled manganese steel, wedged into and supported by

malleable iron chairs which are bolted to the rails at intervals of two feet. This guard rail is in lengths of twenty feet, and may be reversed several times, as will be seen in the illustrations.

The standardisation of points and the reduction in the number of types on each tramway system will not only result in a very considerable saving, but will considerably reduce the number of spare parts and facilitate the execution of repairs and renewals. The standardisation of points and special trackwork generally will

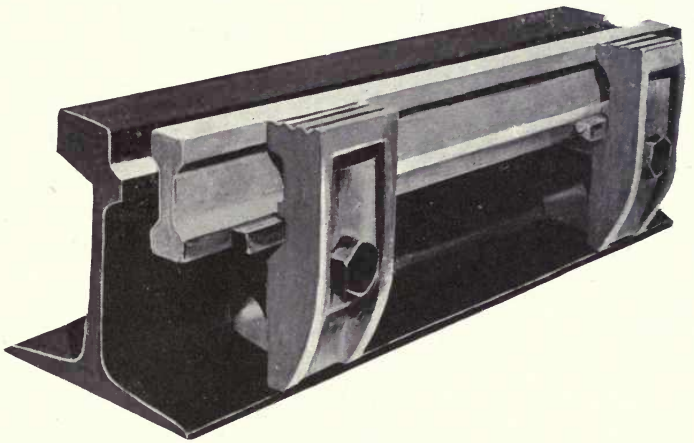


Fig. 144.—"Holt" Patent Guard Rail.

be rendered comparatively easy by the adoption of standard turn-out curves. All curves below at least 150 ft. radius, on tramways, should be easement or spiral curves. By the adoption of spiral curves the path of the car is rendered considerably easier, the wear on the curve rails is lessened, and instead of the car being subjected to a sudden digression from the straight, the transition is gradually performed.

Several suitable forms of spiral curves are in use at the present time, and these differ but slightly from one another, probably the most popular being those arranged by the Lorain Steel Company (Figs. 146), which are suitable for any central radius under 500 ft.

There is little or no need to standardise the ordinary curves which occur on a tramway system, the general

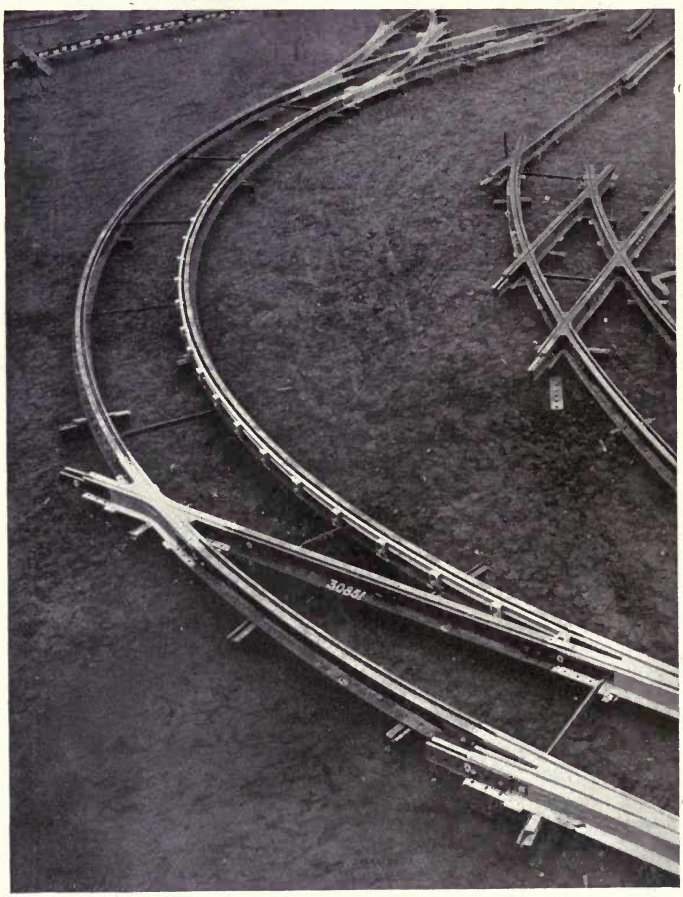


Fig. 145.—Holt's Guard Rail in Track.

practice being to make the curve as flat as possible, but in regard to point or switch spirals, as the accepted description is, it is advisable to limit the number of types as much as possible in order to reduce the different types of points to a minimum. The writer has found it practicable to limit the number of switch spirals to those which may be used in conjunction with 150 ft. radius and 75 ft. radius points. The former is for turn-outs

with a centre radius of from 57 ft. 6 in. to 135 ft. radius, and the latter for turn-outs with a centre radius of from 30 ft. to 50 ft., as given in tables Nos. 3 and 1 respectively. It will be seen that the adoption of the switch spirals in tables Nos. 2 and 4 would necessitate the use of four additional types of points, viz., the left and right hand varieties of the 100 ft. and the 200 ft. radius points. These are quite unnecessary, and the types given above will meet all ordinary requirements. The accompanying diagrams (Figs. 146—160) are self-explanatory, and are fully worked out examples of special track problems, including the use of the spiral tables for curves and junctions, etc.

LORAIN SPIRAL TABLES.

**No. 1.**

STANDARD WITH CURVES 30 FT. TO 37' 6" CEN RADIUS.
MAY BE USED FROM 30 FT. TO 50 FT. CEN. RADIUS.
ENTRANCE RADIUS SPIRAL 289 FEET.
ENTRANCE RADIUS SWITCH SPIRAL 75 FEET.
F = 3' 1½"

| R | A | V | S | X | Y |
|---|---|---|---|---|---|
| 27' 7½" | 18° | 2' 2 ½" | 19' 9 ½" | 28' 5 13/16" | 11' 3 1/16" |
| 30' 1½" | 18° | 2' 2 ½" | 19' 9 ½" | 30' 10 5/16" | 10' 5 3/4" |
| 32' 7½" | 18° | 2' 2 ½" | 19' 9 ½" | 33' 2 7/8" | 9' 8 ½" |
| 35' 1½" | 18° | 2' 2 ½" | 19' 9 ½" | 35' 7 3/8" | 8' 11 ¼" |
| 37' 7½" | 14° | 1' 6 ¼" | 17' 4 5/8" | 38' 0 5/16" | 8' 3 7/16" |
| 40' 1½" | 14° | 1' 6 ¼" | 17' 4 5/8" | 40' 5 7/16" | 7' 8 3/16" |
| 42' 7½" | 10° 30' | 0' 11 7/8" | 14' 11 5/16" | 42' 10 13/16" | 7' 2 1/8" |
| 45' 1½" | 10° 30' | 0' 11 7/8" | 14' 11 5/16" | 45' 4 5/16" | 6' 8 1/16" |
| 47' 7½" | 10° 30' | 0' 11 7/8" | 14' 11 5/16" | 47' 9 13/16" | 6' 3 3/16" |

**No. 2.**

STANDARD WITH CURVES 40 FT. TO 62' 6" CEN. RADIUS.
MAY BE USED FROM 30 FT. TO 70 FT. CEN. RADIUS.
ENTRANCE RADIUS SPIRAL 432 FEET.
ENTRANCE RADIUS SWITCH SPIRAL 100 FEET
F = 3' 7"

| R | A | V | S | X | Y |
|---|---|---|---|---|---|
| 27' 7½" | 22° | 3' 7 1/16" | 27' 0 15/16" | 29' 3 1/16" | 16' 8 3/4" |
| 30' 1½" | 22° | 3' 7 1/16" | 27' 0 15/16" | 31' 6 7/8" | 15' 9 ½" |
| 32' 7½" | 22° | 3' 7 1/16" | 27' 0 15/16" | 33' 10 1/16" | 14' 10 5/16" |
| 35' 1½" | 22° | 3' 7 1/16" | 27' 0 15/16" | 36' 2 ½" | 13' 11 1/16" |
| 37' 7½" | 22° | 3' 7 1/16" | 27' 0 15/16" | 38' 6 5/16" | 12' 11 13/16" |
| 40' 1½" | 18° 20' | 2' 9 3/8" | 24' 8 13/16" | 40' 10 7/16" | 12' 1 5/16" |
| 42' 7½" | 15° | 2' 0 3/4" | 22' 4 1/16" | 43' 2 15/16" | 11' 3 1/16" |
| 45' 1¼" | 15° | 2' 0 3/4" | 22' 4 1/16" | 45' 7 13/16" | 10' 7 7/8" |
| 47' 7¼" | 12° | 1' 5 3/4" | 19' 10 7/8" | 48' 0 3/4" | 10' 0 1/16" |
| 50' 1½" | 12° | 1' 5 3/4" | 19' 10 7/8" | 50' 6 1/8" | 9' 5 13/16" |
| 52' 7½" | 12° | 1' 5 3/4" | 19' 10 7/8" | 52' 11 7/16" | 8' 11 9/16" |
| 55' 1½" | 9° 20' | 1' 0 3/16" | 17' 5 3/8" | 55' 4 15/16" | 8' 6 1/8" |
| 57' 7½" | 9° 20' | 1' 0 3/16" | 17' 5 3/8" | 57' 10 9/16" | 8' 1 1/4" |
| 60' 1½" | 9° 20' | 1' 0 3/16" | 17' 5 3/8" | 60' 4 1/8" | 7' 8 3/8" |
| 62' 7½" | 7° | 0' 7 15/16" | 14' 11 1/16" | 62' 9 13/16" | 7' 4 1/8" |
| 65' 1½" | 7° | 0' 7 15/16" | 14' 11 1/16" | 65' 3 5/8" | 7' 0 7/16" |
| 67' 7½" | 7° | 0' 7 15/16" | 14' 11 1/16" | 67' 9 3/4" | 6' 8 13/16" |

## Spiral Tables for Curves and Junctions.

### No. 3.

STANDARD WITH CURVES 65 FT. TO 125′ CEN. RADIUS.
MAY BE USED FROM 57′ 6″ TO 135 FT. CEN. RADIUS.
ENTRANCE RADIUS SPIRAL 690 FEET.
ENTRANCE RADIUS SWITCH SPIRAL 150 FEET.
F=6′ 4″

| R | A | V | S | X | Y |
|---|---|---|---|---|---|
| 55′ 1½″ | 15° | 3′ 3 5/8″ | 35′ 8 7/8″ | 56′ 6 9/16″ | 21′ 5 1/16″ |
| 57′ 7½″ | 15° | 3′ 3 5/8″ | 35′ 8 7/8″ | 58′ 11 9/16″ | 20′ 9 7/8″ |
| 60′ 1½″ | 15° | 3′ 3 5/8″ | 35′ 8 7/8″ | 61′ 4 1/2″ | 20′ 2 1/8″ |
| 62′ 7½″ | 15° | 3′ 3 5/8″ | 35′ 8 7/8″ | 63′ 9 1/2″ | 19′ 6 5/16″ |
| 65′ 1½″ | 15° | 3′ 3 5/8″ | 35′ 8 7/8″ | 66′ 2 1/2″ | 18′ 10 5/8″ |
| 67′ 7½″ | 15° | 3′ 3 5/8″ | 35′ 8 7/8″ | 68′ 7 7/16″ | 18′ 2 13/16″ |
| 70′ 1½″ | 15° | 3′ 3 5/8″ | 35′ 8 7/8″ | 71′ 0 7/16″ | 17′ 7 1/16″ |
| 72′ 7½″ | 15° | 3′ 3 5/8″ | 35′ 8 7/8″ | 73′ 5 3/8″ | 16′ 11 5/16″ |
| 75′ 1½″ | 15° | 3′ 3 5/8″ | 35′ 8 7/8″ | 75′ 10 3/8″ | 16′ 3 9/16″ |
| 77′ 7½″ | 12° | 2′ 4 3/8″ | 31′ 10 3/16″ | 78′ 3 9/16″ | 15′ 8 5/16″ |
| 80′ 1½″ | 12° | 2′ 4 3/8″ | 31′ 10 3/16″ | 80′ 8 7/8″ | 15′ 2 5/16″ |
| 82′ 7½″ | 12° | 2′ 4 3/8″ | 31′ 10 3/16″ | 83′ 2 1/4″ | 14′ 8 1/16″ |
| 85′ 1½″ | 12° | 2′ 4 3/8″ | 31′ 10 3/16″ | 85′ 7 3/16″ | 14′ 1 13/16″ |
| 87′ 7½″ | 9°20′ | 1′ 7 1/2″ | 27′ 1 1/16″ | 88′ 1 1/16″ | 13′ 8 1/2″ |
| 90′ 1½″ | 9°20′ | 1′ 7 1/2″ | 27′ 1 1/16″ | 90′ 6 1/16″ | 13′ 3 5/8″ |
| 92′ 7½″ | 9°20′ | 1′ 7 1/2″ | 27′ 1 1/16″ | 93′ 0 5/16″ | 12′ 10 3/16″ |
| 95′ 1½″ | 9°20′ | 1′ 7 1/2″ | 27′ 1 1/16″ | 95′ 5 7/8″ | 12′ 5 1/16″ |
| 97′ 7½″ | 9°20′ | 1′ 7 1/2″ | 27′ 1 1/16″ | 97′ 11 1/2″ | 12′ 1 1/16″ |
| 102′ 7½″ | 7° | 1′ 0 1/16″ | 23′ 1 1/2″ | 102′ 11″ | 11′ 5 7/16″ |
| 107′ 7½″ | 7° | 1′ 0 1/16″ | 23′ 1 1/2″ | 107′ 10 9/16″ | 10′ 10 1/8″ |
| 112′ 7½″ | 7° | 1′ 0 1/16″ | 23′ 1 1/2″ | 112′ 10 1/8″ | 10′ 2 13/16″ |
| 117′ 7½″ | 5° | 0′ 7 1/16″ | 19′ 1 13/16″ | 117′ 9 13/16″ | 9′ 8 3/4″ |
| 122′ 7½″ | 5° | 0′ 7 1/16″ | 19′ 1 13/16″ | 122′ 9 9/16″ | 9′ 3 9/16″ |
| 127′ 7½″ | 5° | 0′ 7 1/16″ | 19′ 1 13/16″ | 127′ 9 1/16″ | 8′ 10 5/16″ |
| 132′ 7½″ | 5° | 0′ 7 1/16″ | 19′ 1 13/16″ | 132′ 9 1/8″ | 8′ 5 1/16″ |

### No. 4.

STANDARD WITH CURVES 130 FT. TO 200 FT. CEN. RADIUS.
MAY BE USED FROM 100 FT. TO 200 CEN. RADIUS.
ENTRANCE RADIUS SPIRAL 862 FEET.
ENTRANCE RADIUS SWITCH SPIRAL 200 FEET.
F=7′ 3″

| R | A | V | S | X | Y |
|---|---|---|---|---|---|
| 97′ 7½″ | 12° | 2′ 11½″ | 39′ 9 3/4″ | 98′ 5 3/8″ | 19′ 6 3/16″ |
| 102′ 7½″ | 12° | 2′ 11½″ | 39′ 9 3/4″ | 103′ 4 1/16″ | 18′ 5 3/4″ |
| 107′ 7½″ | 9°20′ | 2′ 0 3/8″ | 34′ 10 13/16″ | 108′ 2 13/16″ | 17′ 5 3/8″ |
| 112′ 7½″ | 9°20′ | 2′ 0 3/8″ | 34′ 10 13/16″ | 113′ 2″ | 16′ 7 3/8″ |
| 117′ 7½″ | 9°20′ | 2′ 0 3/8″ | 34′ 10 13/16″ | 118′ 1 3/16″ | 15′ 9 7/8″ |
| 122′ 7½″ | 9°20′ | 2′ 0 3/8″ | 34′ 10 13/16″ | 123′ 0 3/8″ | 15′ 0 5/16″ |
| 127′ 7½″ | 7° | 1′ 3 7/8″ | 29′ 11 7/16″ | 127′ 11 5/16″ | 14′ 4 3/4″ |
| 132′ 7½″ | 7° | 1′ 3 7/8″ | 29′ 11 7/16″ | 132′ 11 1/2″ | 13′ 9 7/16″ |
| 137′ 7½″ | 7° | 1′ 3 7/8″ | 29′ 11 7/16″ | 137′ 11 1/16″ | 13′ 2 1/16″ |
| 142′ 7½″ | 7° | 1′ 3 7/8″ | 29′ 11 7/16″ | 142′ 10 5/8″ | 12′ 6 15/16″ |
| 147′ 7½″ | 5° | 0′ 9 5/8″ | 24′ 11 3/4″ | 147′ 10 3/8″ | 12′ 1 3/8″ |
| 157′ 7½″ | 5° | 0′ 9 5/8″ | 24′ 11 3/4″ | 157′ 9 7/8″ | 11′ 2 7/8″ |
| 167′ 7½″ | 5° | 0′ 9 5/8″ | 24′ 11 3/4″ | 167′ 9 7/16″ | 10′ 4 7/16″ |
| 177′ 7½″ | 3°20′ | 0′ 5 1/4″ | 19′ 1 15/16″ | 177′ 9 1/8″ | 9′ 8″ |
| 187′ 7½″ | 3°20′ | 0′ 5 1/4″ | 19′ 1 15/16″ | 187′ 8 5/16″ | 9′ 1″ |
| 197′ 7½″ | 3°20′ | 0′ 5 1/4″ | 19′ 1 15/16″ | 197′ 8 1/16″ | 8′ 6″ |

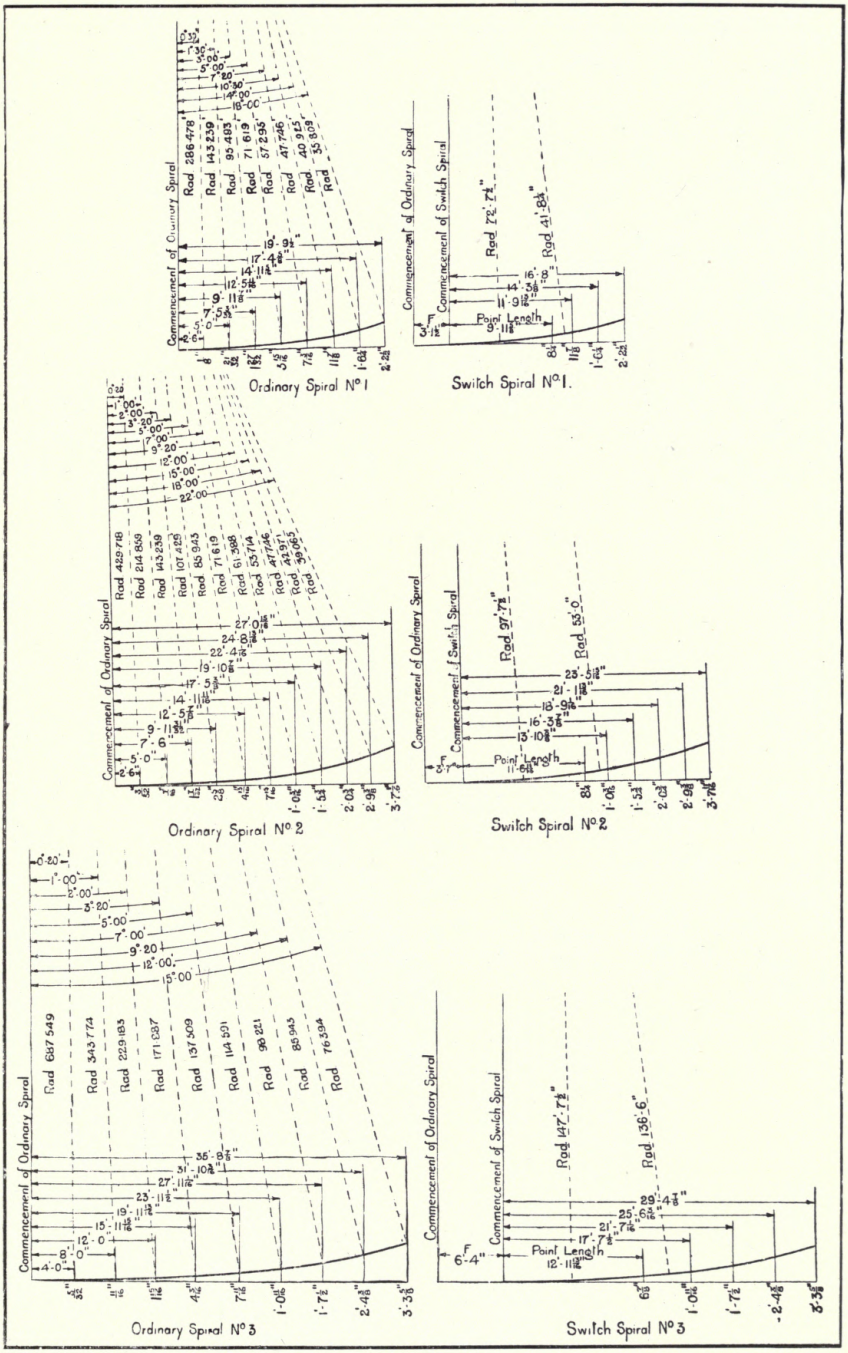



Fig. 146.—Detail of Lorain Ordinary and Switch Spirals Nos. 1, 2, and 3.

EXAMPLES OF SPECIAL TRACK PROBLEMS.

DATA FROM TABLE No. 1.

| | |
|---|---|
| R (Radius) . . . . | = 35′ 1½″ = 35·125 |
| A (Spiral curve arc) . . . | = 18° 00′ |
| V (Offset from tangent) . . | = 2′ 2½″ |
| S . . . . . | = 19′ 9½″ |
| X . . . . . | = 35′ 7⅜″ = 35·6146′ |
| Y . . . . . | = 8′ 11¼″ = 8·9375′ |

NOTE.—Calculations to gauge line on inside rail of curve.

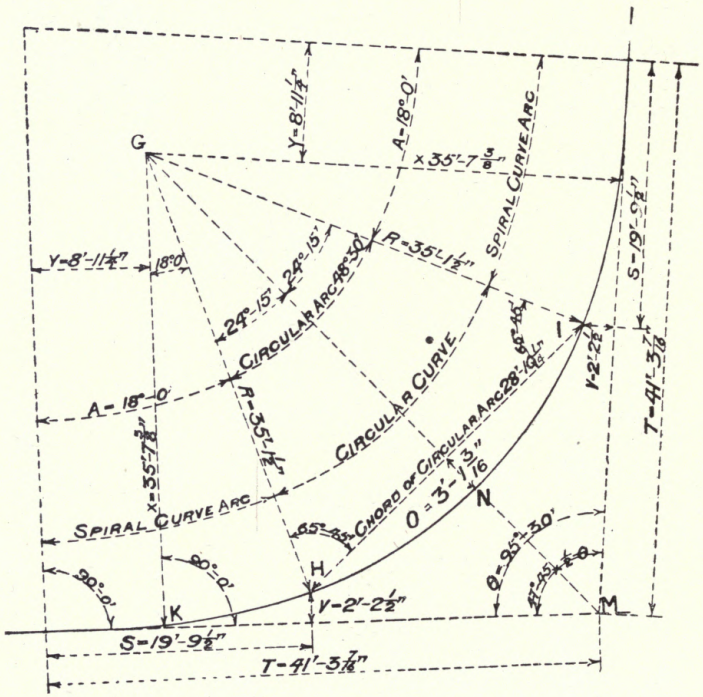



Fig. 147.—Illustrating use of spiral No. 1 in Table, Fig. 146.

CALCULATION.

$\theta$ is found by survey = 95° 30′

(I.) Tangent = (cotangent ½ $\theta$ × X) + Y = (cotangent 47° 45′ × 35·6146′) + 8·9375′ = 41′ $3\frac{7}{16}$″

(II.) Angle of ½ circular arc

(A) A from table No. 1 = 18° 00′ ∴ KGH = 18° 00′

(B) ∴ KGM = 180°00′ − (90°00′ + 47°45′)

KGM = 180°00′ − 137° 45′ = 42° 15′

(C) $HGM = KGM - KGH = 42° 15' - 18° 00' = 24° 15'$

(D) $\therefore$ Circular arc $= 2 \times 24° 15' = 48° 30'$

(III.) Length of chord of circular arc

Angle of circular arc $= 48° 30'$

Radius of circular arc $= R = 35{\cdot}125'$ (Table No. 1)

Length of chord of circular arc

$$= 2R \times \sin \frac{\text{angle of circular arc}}{2}$$

$$= 2 \times 35{\cdot}125' \times \sin \frac{48° 30'}{2}$$

$$= 2 \times 35{\cdot}125' \times 0{\cdot}4107189 = 28' \ 10\tfrac{1}{4}''$$

(IV.) Length of offset from chord of circular arc

$$= O = R - R \times \cos \frac{\text{angle of circular arc}}{2}$$

$$= 35{\cdot}125' - 35{\cdot}125' \times {\cdot}911762$$

$$= 35{\cdot}125' - 32{\cdot}026'$$

$$= 3' \ 1\tfrac{3}{16}''$$

(V.) To find external distance NM

(A) $GM = \dfrac{X}{\sin \frac{1}{2}\theta} = \dfrac{35{\cdot}6146'}{\sin 47° 45'} = \dfrac{35{\cdot}6146'}{{\cdot}7402}$

$= 48' \ 1\tfrac{5}{16}''$

(B) $NM = GM - GN = 48' \ 1\tfrac{5}{16}'' - 35' \ 1\tfrac{1}{2}''$

$= 12' \ 11\tfrac{13}{16}''$

DATA FROM TABLE No. 3.

| | |
|---|---|
| R (Radius) . . . . | $= 55' \ 1\frac{1}{2}'' = 55{\cdot}125'$ |
| A (Spiral curve arc) . . . | $= 15° \ 00'$ |
| V (Offset from tangent) . . | $= 3' \ 3\frac{5}{8}''$ |
| S . . . . . | $= 35' \ 8\frac{7}{8}''$ |
| X . . . . . | $= 56' \ 6\frac{9}{16}'' = 56{\cdot}5469'$ |
| Y . . . . . | $= 21' \ 5\frac{11}{16}'' = 21{\cdot}4739'$ |

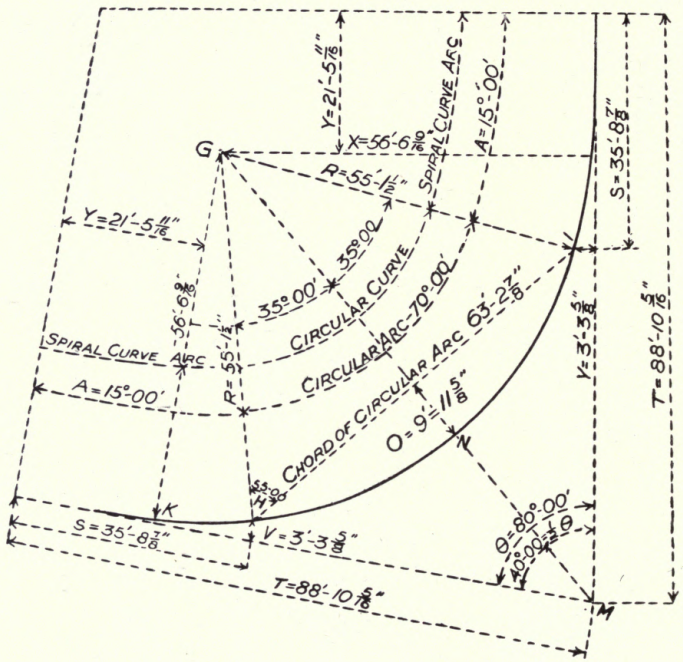



Fig. 148.—Illustrating use of spiral No. 3 in Table, Fig. 146.

CALCULATION.

$\theta$ is found by survey $= 80° \ 00'$

(I.) Tangent $=$ (cotangent $\frac{1}{2}\ \theta \times$ X) $+$ Y $=$ (cotangent $40° \ 00' \times 56{\cdot}5469'$) $+ 21{\cdot}4739' = 88' \ 10\frac{5}{16}''$

(II.) Angle of $\frac{1}{2}$ circular arc

(A) A from table No. $3 = 15° \ 00'$ $\therefore$ KGH $= 15° \ 00'$

(B) KGM $= 180° \ 00' - (90° \ 00' + 40° \ 00')$

KGM $= 180° \ 00' - 130° \ 00' = 50° \ 00'$

(C) $HGM = KGM - KGH = 50° 00' - 15° 00' = 35° 00'$

(D) Circular arc $= 2 \times 35° 00' = 70° 00'$

(III.) Length of chord of circular arc

Angle of circular arc $= 70° 00'$

Radius of circular arc $= R = 55{\cdot}125'$ (Table No. 3)

Length of chord of circular arc

$$= 2R \times \sin \frac{\text{angle of circular arc}}{2}$$

$$= 2 \times 55{\cdot}125' \times \sin \frac{70° 00'}{2}$$

$$= 2 \times 55{\cdot}125' \times {\cdot}573576 = 63' \, 2\tfrac{7}{8}''$$

(IV.) Length of offset from chord of circular arc

$$= O = R - R \times \frac{\cos \text{ angle of circular arc}}{2}$$

$$= 55{\cdot}125' - 55{\cdot}125' \times {\cdot}8191520$$

$$= 55{\cdot}125' - 45{\cdot}156'$$

$$= 9' \, 11\tfrac{5}{8}''$$

(V.) To find external distance NM

(A) $GM = \frac{X}{\sin \frac{1}{2}\theta} = \frac{56{\cdot}5469'}{\sin 40° 00'} = \frac{56{\cdot}5469'}{{\cdot}6427} = 87' \, 11\tfrac{13}{16}''$

(B) $NM = GM - GN = 87' \, 11\tfrac{15}{16}'' - 55' \, 1\tfrac{1}{2}'' = 32' \, 10\tfrac{5}{16}''$

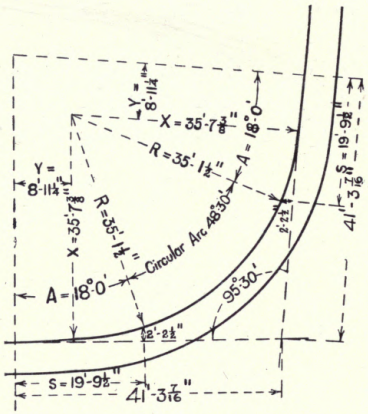



Fig. 149.
Single track easement curve.
For calculations, see Fig. 147.

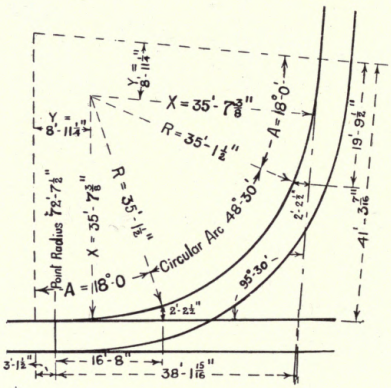



Fig. 150.
Single track easement curve with junction at one end.
Tangent for switch spiral as in Fig. 147.
Tangent for ordinary spiral as in Fig. 147.

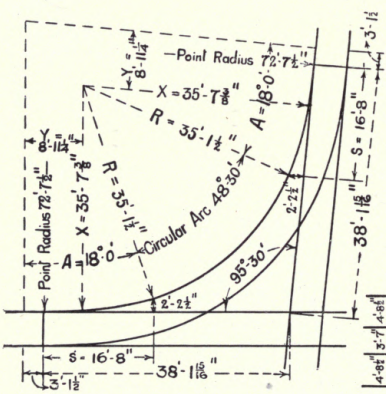



Fig. 151.
Single track easement curve with single junction at both ends.
Full tangent from Fig. 147, 41′ $3\frac{7}{16}$″.
Deduct 3′ $1\frac{1}{2}$″ (see table No. 1).
Tangent for switch spiral 38′ $1\frac{15}{16}$″.

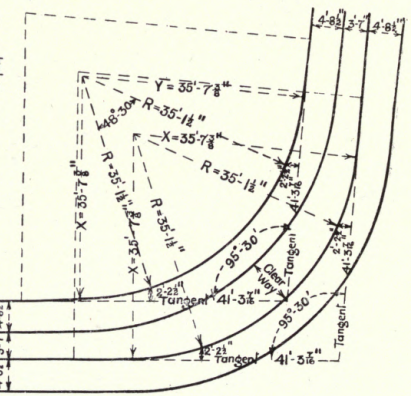



Fig. 152.
Double track easement curve showing widening clearway at centre.

## Double Track Easement Curve with Junction at one End.

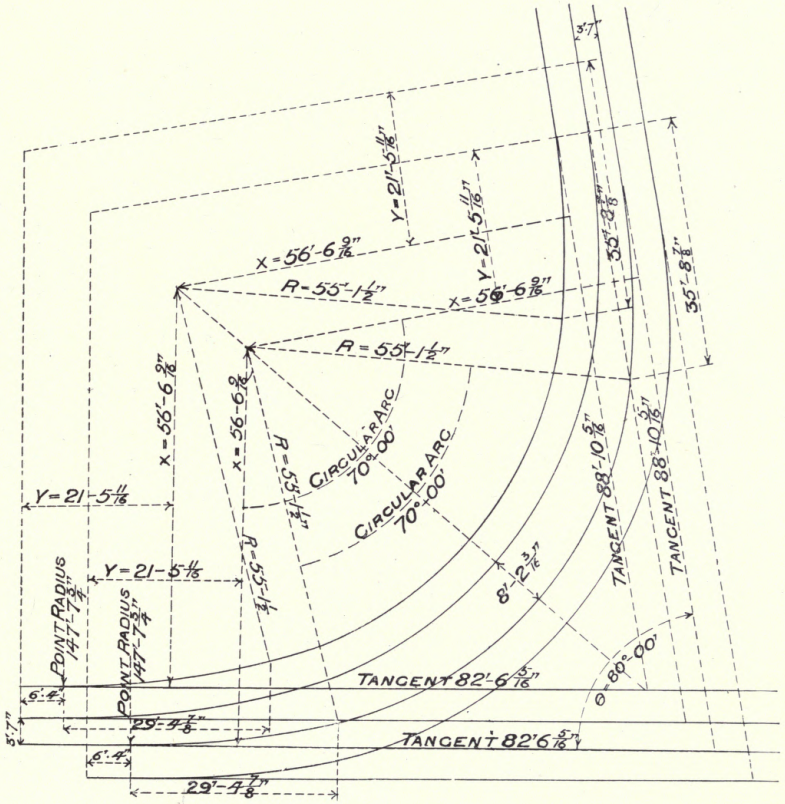



Fig. 153.

| | |
|---|---|
| Full tangent for ordinary spiral from Fig. 148 | 88′ $10\frac{5}{16}$″ |
| For switch spiral tangent deduct 6′·4″ (see table No. 3) | 6′ 4″ |
| Tangent for switch spiral. | 82′ $6\frac{5}{16}$″ |

FIG. 154. EQUILATERAL LOOP END.

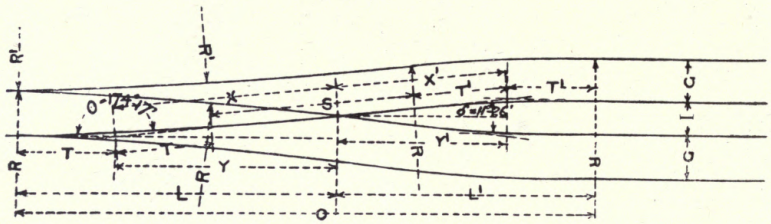



Fig. 154. (Equilateral loop-end.)

CALCULATIONS FOR FIG. 154.

Given:—Centre radius 200′ 0″, crossing angle $\delta$ 1 in 5 (11° 26′), gauge 4′ $8\frac{1}{2}$″, centre way 3′ 7″

Then:—$\theta = 180° 0' - 5° 43' = 174° 17'$

$R = 200' 0'' + \frac{1}{2} G = 202' 4\frac{1}{4}''$

$R' = 200' 0'' - \frac{1}{2} G = 197' 7\frac{3}{4}''$

$T = R \times \tan \frac{\delta}{4} = 10' 1\frac{1}{4}''$

$T' = R' \times \tan \frac{\delta}{4} = 9' 10\frac{7}{16}''$

$X = \frac{\frac{1}{2} G}{\sin \frac{1}{2} \delta} = 23' 7\frac{21}{32}''$

$Y = \frac{\frac{1}{2} G}{\tan \frac{1}{2} \delta} = 23' 6\frac{7}{32}''$

$X' = \frac{\frac{1}{2} I}{\sin \frac{1}{2} \delta} = 17' 11\frac{7}{8}''$

$Y' = \frac{\frac{1}{2} I}{\tan \frac{1}{2} \delta} = 17' 10\frac{25}{32}''$

$L = T + Y = 33' 7\frac{15}{32}''$

$L' = T' + Y' = 27' 9\frac{7}{32}''$

$O = L + L' = 61' 4\frac{11}{16}''$

$S = (X + X') - (T + T') = 21' 7\frac{27}{32}''$

FIGS. 155 AND 156. (CURVED POINTS AND STRAIGHT CROSSINGS.)

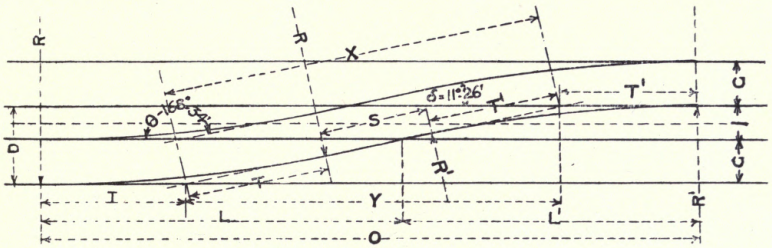



Fig. 155. (Cross-over.)

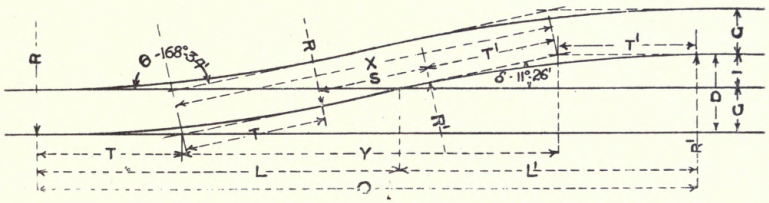



Fig. 156. Lateral turnout.

Given:—Centre radius 150′ 0″, crossing angle $\delta$ 1 in 5 (11° 26′) gauge 4′ $8\frac{1}{2}$″, centre way 3′ 7″

Then:—$\theta = 180° 0' - 11° 26' = 168° 34'$

$R = 150' 0'' + \frac{1}{2} G = 152' 4\frac{1}{4}''$

$R' = 150' 0'' - \frac{1}{2} G = 147' 7\frac{3}{4}''$

$$T = R \times \tan \frac{\delta}{2} = 15' 3''$$

$$T' = R' \times \tan \frac{\delta}{2} = 14' 9\tfrac{3}{8}''$$

$D = I + G = 8' 3\frac{1}{2}''$

$$X = \frac{D}{\sin \delta} = 41' 9\tfrac{15}{16}''$$

$$Y = \frac{D}{\tan \delta} = 41' 0''$$

$$O = 2\left(R - \frac{G}{2}\right) \tan \frac{\delta}{2} + D \operatorname{cotan} \delta$$

$$= 71' 0\tfrac{3}{8}''$$

$$L = R \tan \frac{\delta}{2} + G \operatorname{cotan} \delta = 38' 6\tfrac{3}{8}''$$

$$L' = (R - G) \tan \frac{\delta}{2} + I \operatorname{cotan} \delta = 32' 6''$$

$$S = X - (T + T') = 11' 9\tfrac{9}{16}''$$

LATERAL TURNOUT WITH STRAIGHT POINTS AND STRAIGHT CROSSING.

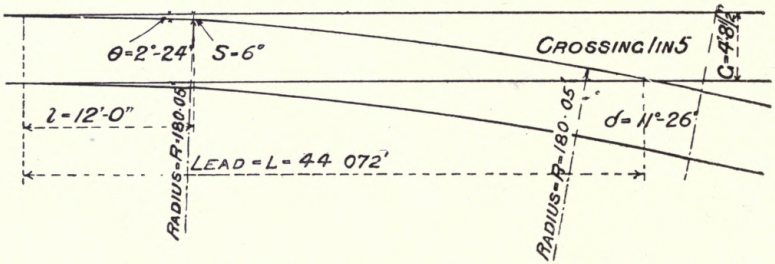



Fig. 157.

$$\text{To find} \begin{cases} \text{R} = \text{Radius of curved lead.} \\ \text{L} = \text{Lead of crossing.} \end{cases}$$

$\text{G} =$ gauge of track $= 4' \; 8\frac{1}{2}''$

$l =$ length of point $= 12' \; 0''$

$\theta =$ angle of point $= \left(\sin \theta = \dfrac{\text{S}}{l}\right) = 2° \; 24'$

$\delta =$ crossing angle $= 11° \; 26'$ (1 in 5)

$\text{S} =$ spread of point $= 6''$

$\text{K} =$ length of crossing leg $= 4' \; 0''$

$$\text{R} = \frac{\text{G} - \text{S} - \text{K} \sin \delta}{\cos \theta - \cos \delta}$$

$$= \frac{4{\cdot}708 - {\cdot}5 - (4 \sin 11° \, 26')}{0{\cdot}9991228 - 0{\cdot}9801560}$$

$$= 180{\cdot}05 \text{ feet}$$

$$\therefore \text{L} = l + \frac{\text{G} - \text{S} - \text{K} \sin \delta}{\tan \frac{1}{2} (\theta + \delta)} + 4 \cos \delta$$

$$\text{L} = 12 + \frac{4{\cdot}708 - {\cdot}5 - (4 \times \sin 11° \, 26')}{\tan \frac{1}{2} (2° \; 24' + 11° \; 26')} + 3{\cdot}92$$

$$\text{L} = 44{\cdot}072 \text{ feet}$$

LATERAL TURNOUT WITH STRAIGHT POINTS AND CURVED CROSSING.

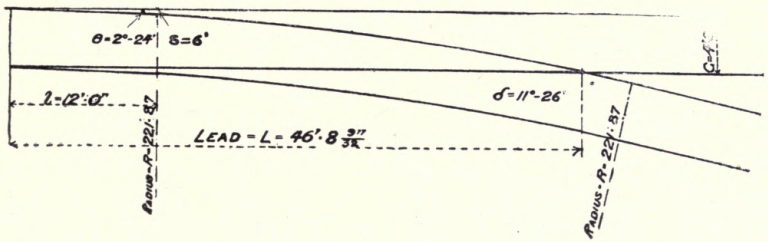



Fig. 158.

$$\text{To find} \begin{cases} \text{R} = \text{Radius of curved lead.} \\ \text{L} = \text{Lead of crossing.} \end{cases}$$

$\text{G}$ = gauge of track $4' \; 8\frac{1}{2}''$

$l$ = length of point $12' \; 0''$

$\theta$ = angle of point $= \left(\sin \theta = \dfrac{\text{S}}{l}\right) \; 2° \; 24'$

$\delta$ = tangential angle of crossing = (1 in 5) $= 11° \; 26'$

$\text{S}$ = spread of point $= 6''$

$$\therefore \text{R} = \frac{\text{G} - \text{S}}{\cos \theta - \cos \delta}$$

$$= \frac{4{\cdot}7083 - {\cdot}5}{\cos 2° \; 24' - \cos 11° \; 26'}$$

$$= 221{\cdot}87 \text{ feet}$$

$$\therefore \text{L} = l + \frac{\text{G} - \text{S}}{\tan \frac{1}{2} (\theta + \delta)}$$

$$\text{L} = 12 + \frac{4{\cdot}708 - {\cdot}5}{\tan 6° \; 55'}$$

$$\text{L} = 46{\cdot}69 \text{ feet}$$

### To Set Out a Simple Curve from Observed Angle and Given Radius.

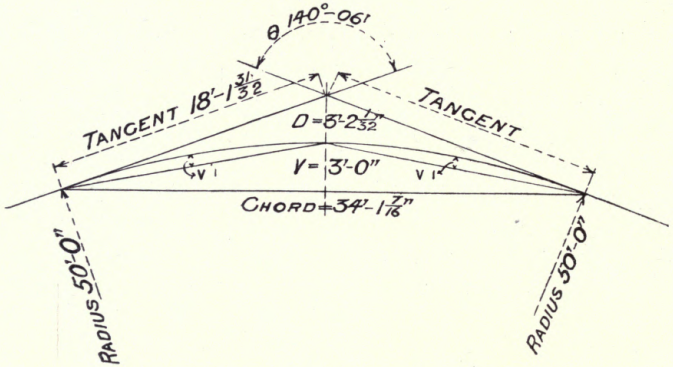



Fig. 159.

Let angle of intersection $= \theta = 140° 06'$ Radius $= R = 50' 0''$

(A) Tangent $= R \times \text{cotan } \frac{1}{2} \theta = 50' \times \text{cotan } 70° 03' = 50' \times \cdot 3629 = 18' 1\frac{3}{4}''$

(B) Chord $= 2 (R \times \text{cosine } \frac{1}{2} \theta) = 2 (50' \times \text{cosine } 70° 03') = 2 \times 50 \times \cdot 3412 = 34' 1\frac{7}{16}''$

(C) Versine $= V = R \times \text{covers } \frac{1}{2} \theta = 50' \times \text{covers } 70° 03' = 50' \times \cdot 06 = 3' 0''$

(D) External dist.: $D = R \times (\text{cosec } \frac{1}{2} \theta - 1) = 50' \times (1 \cdot 063 - 1 \cdot 000) = 50' \times \cdot 063 = 3' 1\frac{13}{16}''$

(E) To find further points on curve join ends of curve to centre of curve and at centres erect versines $V' = \frac{1}{4} V$; further chords may be formed between known points and $V^2$ will $= \frac{1}{4} V^1$, $V^3$ will $= \frac{1}{4} V^2$ ad infin.

## To Find Tangent Length of a Curve of Known Radius without Using a Theodolite.

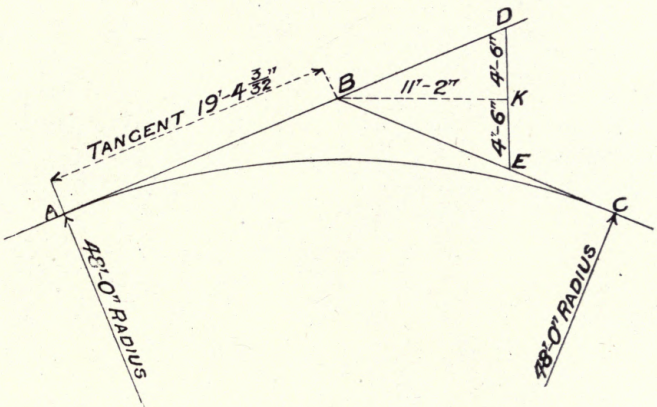



Fig. 160.

(A) Produce tangent line A B any convenient length to D

(B) Make B E = B D

(C) Bisect D E at K

(D) Measure BK and KE (BK = 11′ 2″ and KE is 4′ 6″ in given example)

Assume radius (48′ 0″ in given example)

Then tangent AB or BC $= \dfrac{R \times KE}{BK}$

$= \dfrac{48' 0'' \times 4' 6''}{11' 2''} = 19' 4\frac{3}{32}''$

# APPENDIX A

## SPECIAL TRACKWORK CALCULATIONS

By Ernest Larmuth

The writer has often been asked to explain his methods of calculation, and the following notes are written in the hope that they will prove to be of service to those interested in tramway trackwork. Whilst possibly not covering every conceivable problem, the examples are sufficient to cover most of the problems likely to require solution by permanent way engineers. The calculations necessary for the solution of problems in special work for tramways do not require a deep knowledge of mathematics so much as a thorough training in a few elementary principles, and also the ability to see how and where these principles apply.

Examples I., II., III. will cover practically all that is required where the main tracks are both straight. Examples IV. to VIII. refer to problems in which it is necessary to comply with special conditions, such as working to existing curve tracks, curved main tracks, etc. The part of these notes on reverse curves is relatively simple, but it has been included in order to make the treatment of the subject more complete. In the diagrams and explanations the use of definite examples has been avoided, the object being to make the formulæ as general as possible.

Each example should be carefully dealt with by actual calculation, and afterwards checked by drawing to scale. By so doing, far more benefit will be obtained (through failures caused by laying down impossible conditions) than by merely checking figures which have been previously worked out.

Example I.—(Fig. 1a) *Plain Curves.*

The calculations for circular curves connecting two intersecting lines present no difficulty:

$$AO = CO = R.$$

$$AB = BC = \text{Tangent} = R \tan \frac{\alpha}{2}.$$

$$AC = \text{Chord} = 2R \sin \frac{\alpha}{2}.$$

$$BS = \text{Exsecant} = R \sec \frac{\alpha}{2} - R.$$

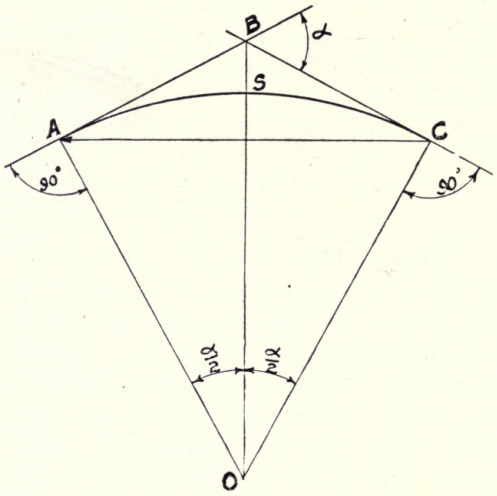



Fig. 1A.

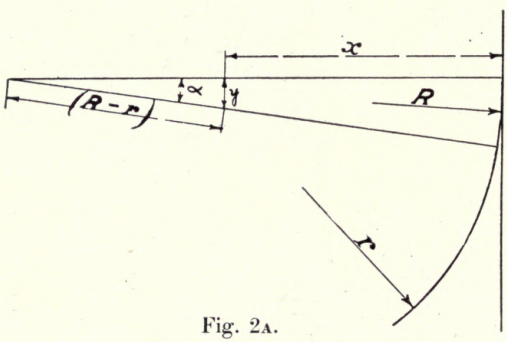



Fig. 2A.

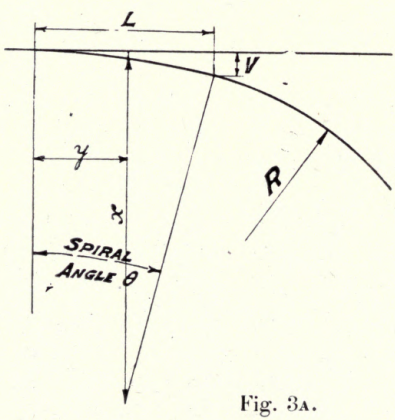



Fig. 3A.

When, however, compound curves have to be dealt with, the problems are not quite so simple. By the term "compound curve" is meant a curve (connecting two intersecting lines) which is not of uniform radius throughout. There is usually, however, a central portion of the curve which is of uniform curvature, and the radius of this portion is generally termed the radius of the curve. The central radius is also, generally speaking, the minimum radius on any curve.

The remainder of the curve may be composed of one or more sections of varying radii, forming spirals or easement curves. In whatever manner the curve is built up, the first operation, where possible, is to determine the co-ordinates of the centre of the main curve. These can be denoted by the letters $x$ $y$.

Methods of calculating the co-ordinates $x$ $y$ are given below:

Let R$r$ (Fig. 2A) be the radii of the curves,
Then $(R - r) \sin \alpha = y$.
$R - (R - r) \cos \alpha = x$.

If two or more curves intervene between the straight line and the central curve, the above operation can be repeated until the co-ordinates for the centre of the main curve are obtained.

If a circular arc is to be fitted to the end of a spiral curve, details of which are known, the following will give the required co-ordinates (Fig. 3A):

Values of L, V, and $\theta$ are given in the details of spiral.

$y = L - R \sin \theta$.
$x = V + R \cos \theta$.

EXAMPLE II. — (A) In cases where the curve is symmetrical, *i.e.*, the co-ordinates referred to each tangent line are the same, the following formulæ will give all the information that is required (Fig. 4A):

Tangent $= T = x \tan \frac{\alpha}{2} + y$.

Chord $= C = 2T \cos \frac{\alpha}{2}$.

Exsecant $= E = x \sec. \frac{\alpha}{2} - R$.

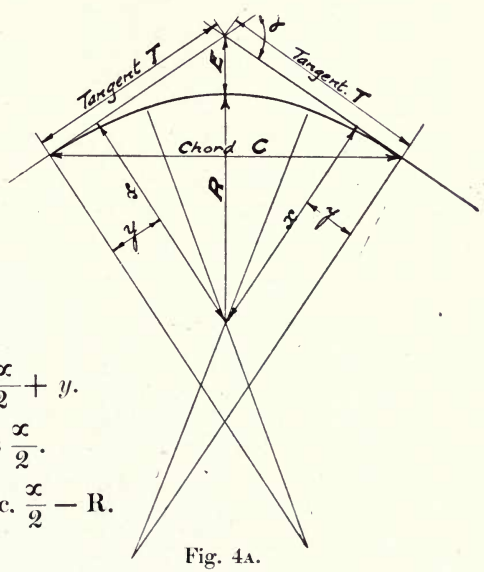



Fig. 4A.

The co-ordinate $x$ is usually calculated to the gauge line, and as used above would give tangent lengths from gauge line intersections. If it is desired to obtain lengths from the intersections of any other lines (say centre lines of track) to the tangent points of the curves, the $x$ dimension will require to be increased or decreased accordingly, but the $y$ dimension will remain unchanged.

EXAMPLE III.—(B) In cases where the curve is not symmetrical with relation to both lines, the following is, in the writer's opinion, the quickest and simplest of several solutions.

[NOTE.—The want of symmetry may be caused by alterations in width of centre-way or altered position of one track. It is also sometimes necessitated by some condition limiting the design in a new lay-out.]

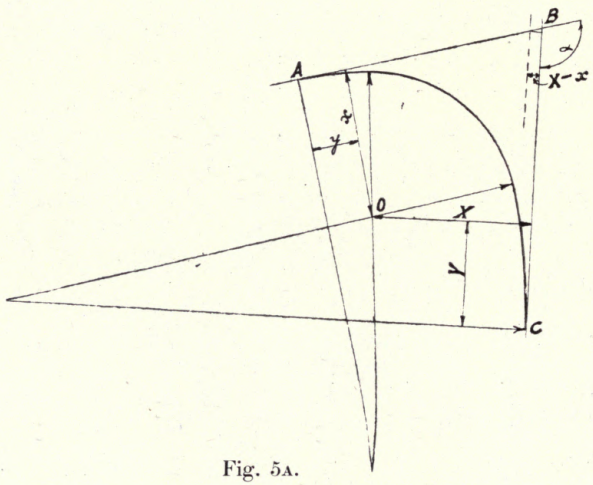



Fig. 5A.

Let X, Y, $x$, $y$ be the co-ordinates to the two tangent lines, and let angle of intersection $= \alpha$ (Fig. 5A).

(*a*) Then $AB = x \tan \frac{\alpha}{2} + (X - x) \operatorname{cosec} (180 - \alpha) + y.$

(*b*) $BC = x \tan \frac{\alpha}{2} + (X - x) \operatorname{cotan} (180 - \alpha) + Y.$

Having thus obtained the tangent lengths, there is no difficulty in calculating the chord length AC and the distance BO from which the exsecant can be obtained.

This method is extremely useful in calculating dimensions relating to track centre lines where the distances from centre to centre of tracks are not alike on two roads, although the curve itself is symmetrical with respect to gauge lines.

In equation (*b*) the $+^{ve}$ sign before the second member will become negative when $\alpha$ is less than 90°.

The following examples are much more complicated, but are of especial value where new track is required to connect to existing curves.

EXAMPLE IV.—(1) To connect a straight line and a curve at a given point by a uniform circular curve (Fig. 6A).

Let PB be the straight line.
PA the tangent to existing curve at A.
Angle BPA = $180° - \alpha$.

Then $R = PA \cot an \frac{\alpha}{2}$

$BP = PA$.

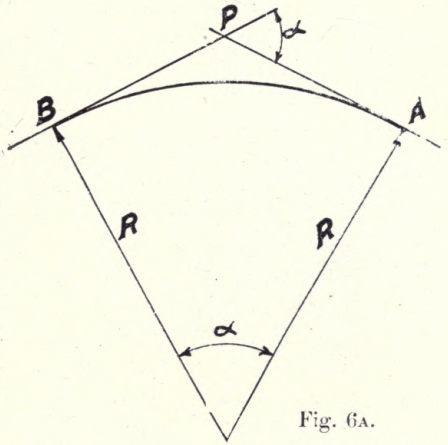


Fig. 6A.

EXAMPLE V.—If, however, a compound or spiralised curve is required, the solution is a little more difficult (Figs. 7A and 8A).

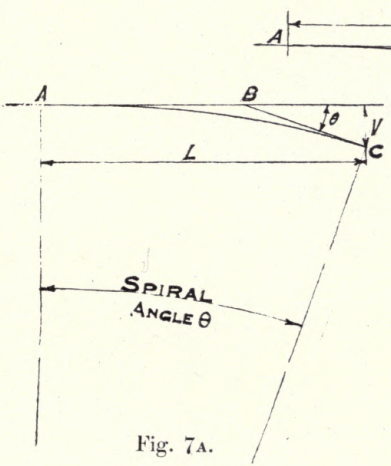


Fig. 7A.

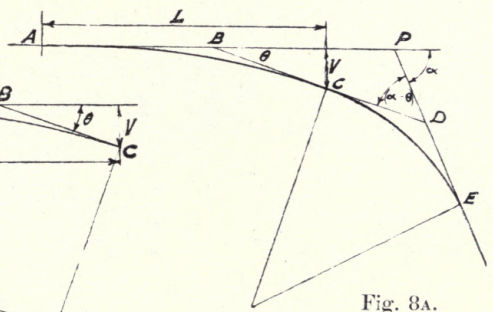


Fig. 8A.

Having decided on the spiral to be used, and determined L, V, and $\theta$, the first operation is to determine the tangent lengths to the spiral.

These are given by the following equations:

$AB = L - V \text{ cotan } \theta.$
$BC = V \text{ cosec } \theta.$
E = junction of new and existing curves.
AP and PE are tangents to curve required.
$\alpha$ = angle of intersection.

Required to find radius of new curve knowing length PE and $\alpha$:

Let $PE = Z = PD + x$ where $DE = x = CD.$

$$PD = BD \frac{\sin \theta}{\sin \alpha} = (V \text{ cosec } \theta + x) \frac{\sin \theta}{\sin \alpha}.$$

$$PE = Z = (V \text{ cosec } \theta + x) \frac{\sin \theta}{\sin \alpha} + x.$$

$$x \left(1 + \frac{\sin \theta}{\sin \alpha}\right) = Z - V \left(\frac{1}{\sin \alpha}\right).$$

$$x = \frac{Z - V \text{ cosec } \alpha}{\left(1 + \frac{\sin \theta}{\sin \alpha}\right)}.$$

$$R = x \text{ cotan } \frac{(\alpha - \theta)}{2}.$$

$$BP = BD \frac{\sin (\alpha - \theta)}{\sin \alpha} = (V \text{ cosec } \theta + x) \frac{\sin (\alpha - \theta)}{\sin \alpha}.$$

Tangent length $AP = AB + BP.$

$$= L - V \text{ cotan } \theta + (V \text{ cosec } \theta + x) \frac{\sin (\alpha - \theta)}{\sin \alpha}.$$

The result of the last equation can be checked by calculating the co-ordinates for the radius R determined and then calculating the tangent lengths as previously described. (See Example III.)

EXAMPLE VI.—(2) Given one tangent length and position of centre of main curve, to determine the other tangent length for given radius to connect to main curve (Fig 9A).

Given $z$, $y$, $x$, $r$, R, $\alpha$ to determine XY and tangent length PA.

$$\frac{x}{z} = \tan \beta.$$

$$x \text{ cosec } \beta = PO.$$

$$(x \text{ cosec } \beta) \sin (180 - \alpha - \beta) = CO = X.$$

$$(x \text{ cosec } \beta) \cos (180 - \alpha - \beta) = PC.$$

Then $$\frac{R - X}{R - r} = \cos \theta$$

$$(R - r) \sin \theta = Y.$$

$$PA = PC + Y.$$

Knowing the position of centre O with relation to P it is an easy matter to calculate the exsecant.

The chord length AD is calculated from the triangle APD, of which we now know AP, PD, and angle APD.

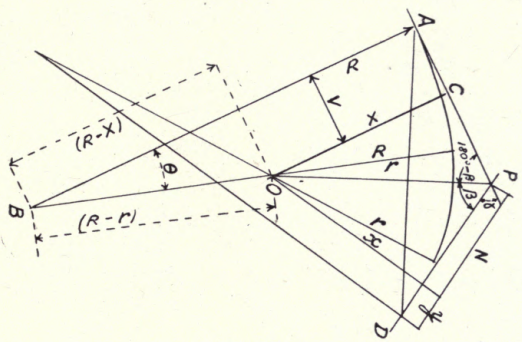



Fig. 9A.

EXAMPLE VII.—(3) The next example with which I propose to deal is to connect two curves by means of a curve of different

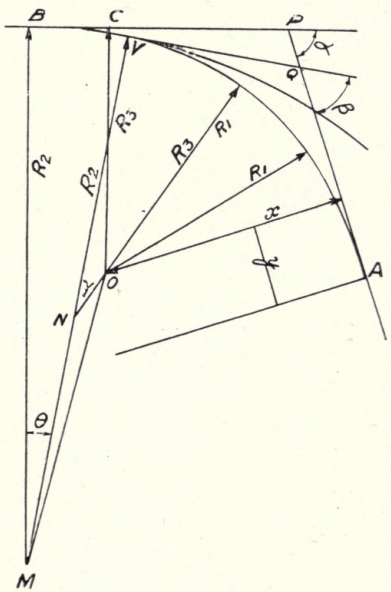



Fig. 10A.

radius, being given the tangent lengths and angle, also the radii of the three curves (Fig. 10A):

Given PA, PB, $x$, $y$, $R_1$, $R_2$, $R_3$ $\alpha$ to find $\theta$, $\gamma$, $\beta$.
From PA, $x$, $y$ calculate PO, CO, PC (see Example VI.).

Then $\dfrac{PB - PC}{R_2 - CO} = \tan BMO.$

$(R_2 - CO)$ secant BMO $= MO.$

$MN = R_2 - R_3.$

$NO = R_3 - R_1.$

From the three sides MN, NO, MO the angles can be calculated.

Then $\angle BMO - \angle NMO = \theta.$

$$180 - \angle ONM = \angle NOM + \angle NMO = \alpha.$$

$$\beta = \alpha - \theta.$$

Having determined the angles, it is now a matter for straightforward calculation to determine the new tangent length QV, and any other details (chord, exsecant, etc.) which may be required.

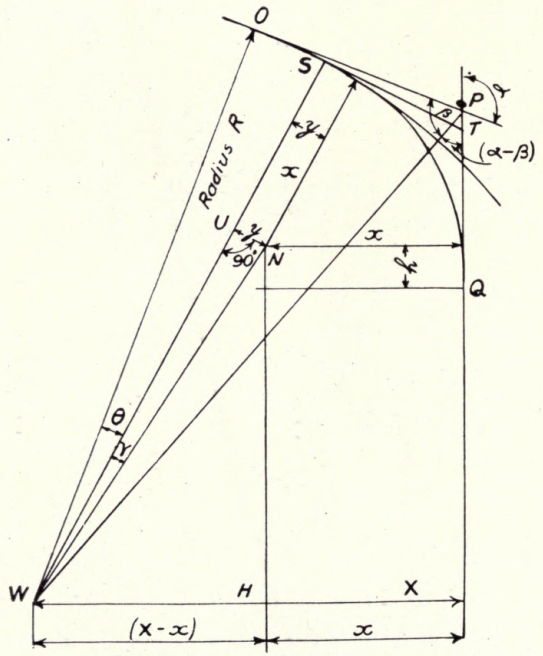



Fig. 11A.

EXAMPLE VIII.—(4) The next case to be dealt with is a curve connecting two main tracks—one of which is curved (Fig. 11A).

Let OP, PQ represent the two tangents intersecting at P.
Let $\alpha$ = angle of intersection.
Let O = tangent point to radius R.

Assume the connecting curve to be symmetrical radius $r$ spiralised or compounded at ends.

Let $x$ $y$ be co-ordinates to centre of connecting curve from tangents ST and PTQ.

Let S = point of contact of two curves.

W = centre of curve radius R.

Then SW = R.

SU = $x$.

UW = R − $x$.

UZ = $y$.

$$\tan \gamma = \frac{\text{UZ}}{\text{UW}}.$$

ZW = UW sec $\gamma$.

To determine angle $\theta$.

$$\frac{\text{OW}}{\text{OP}} = \frac{\text{R}}{\text{OP}} = \tan \beta.$$

OW cosec $\beta$ = PW.

Let X = perpendicular distance from W on line PQ extended.

X = PW sin $(\alpha - \beta)$ = OW (cosec $\beta$) sin $(\alpha - \beta)$.

Draw ZH parallel to PQ.

$$\text{Then } \frac{(\text{X} - x)}{\text{ZW}} = \cos \angle \text{ZWH}.$$

Angle HWO = $180° - \alpha = \theta + \gamma + \angle$ZWH.

$\theta = 180° - \alpha - \gamma - \angle$ZWH.

Knowing the angle $\theta$ we are now able to determine the position of the point S and direction of the tangent to the curve at S, and the calculations resolve themselves into those for a symmetrical curve as previously given. (Example II.)

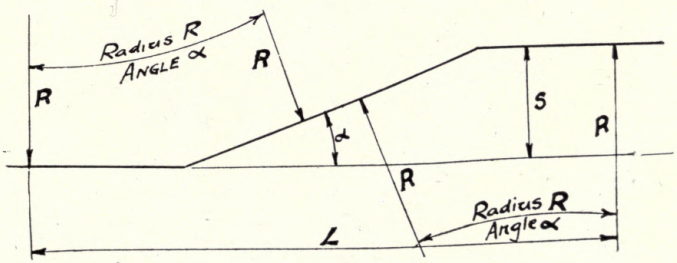



Fig. 12A.

Example IX.—*Reverse Curves.* It is sometimes necessary to use a reverse curve on tracks where the centre line is moved

parallel to itself. There are three or four cases, which may be considered as typical.

(1) Ordinary reverse curve with portion of straight track in centre (Fig. 12A).

Where L is not fixed, radius R and angle $\alpha$ can be decided upon. Length L is given by the following equation :

$$L = 2R \tan \frac{\alpha}{2} + S \operatorname{cotan} \alpha .$$

EXAMPLE X.—(2) Assume the length L to be fixed and also the length of the straight ($2l$) it is desirable to have in centre to find R and $\alpha$ (Fig. 13A).

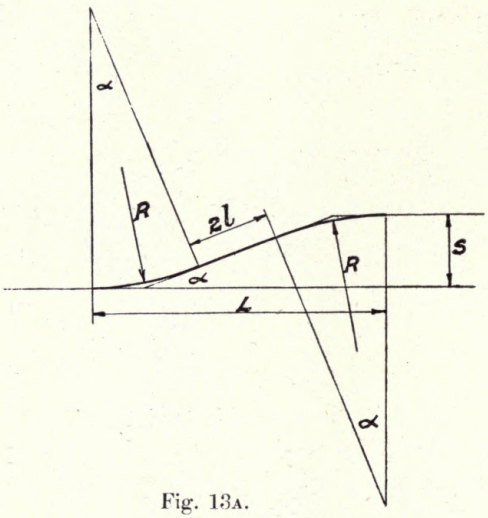



Fig. 13A.

The distance between the two centres $= 2\sqrt{R^2 + l^2}$.

Then $(2\sqrt{R^2 + l^2})^2 = L^2 + (2R - S)^2$.

$$4R^2 + 4l^2 = L^2 + 4R^2 + S^2 - 4RS,$$

$$R = \frac{L^2 - 4l^2 + S^2}{4S} \qquad (1).$$

$$\alpha = \cos^{-1} \frac{2R - S}{2\sqrt{R^2 + l^2}} - \tan^{-1} \left(\frac{l}{R}\right) \qquad (2).$$

The quantities on the RH side of equation (1) are known, therefore R can be determined.

By substituting for R, S and $l$ in equation (2) the angle $\alpha$ can be determined.

EXAMPLE XI.—(3) To determine the length of a reverse curve of given radius between two parallel lines (Fig. 14A):

$$\text{Cos } \alpha = \frac{2R - S}{2R}.$$

$$L = 2R \sin \alpha .$$

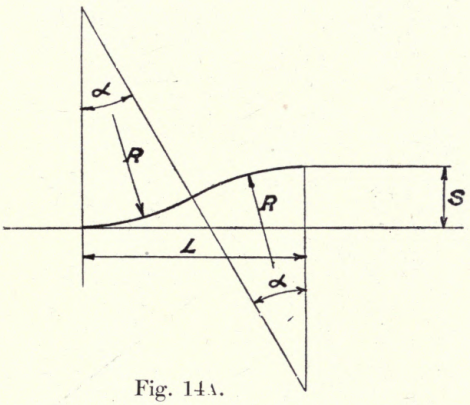



Fig. 14A.

EXAMPLE XII.—(4) To determine the radius of a reverse curve between two parallel lines, length being fixed (Fig. 15A):

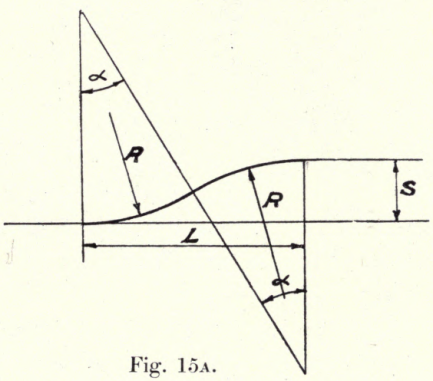



Fig. 15A.

$$(2R)^2 - L^2 = (2R - S)^2$$

$$4R^2 - L^2 = 4R^2 - 4RS + S^2$$

$$4RS = L^2 + S^2$$

$$R = \frac{L^2 + S^2}{4S}$$

$$\text{Angle } \alpha = \sin^{-1}\left(\frac{L}{2R}\right).$$

To determine a reverse curve between two intersecting lines PA, PB, the tangent point C being fixed at one end (Fig. 16A):

Let PA, PB be the intersecting lines.
Let angle BPA $= \alpha$.
Let C $=$ tangent point to radius $R^1$.
CO $=$ radius $R^1$.
Then PO $= \sqrt{CO^2 + PC^2}$.

$$\text{Tan } \beta = \frac{CO}{PC}.$$

$$\gamma = \alpha - \beta$$

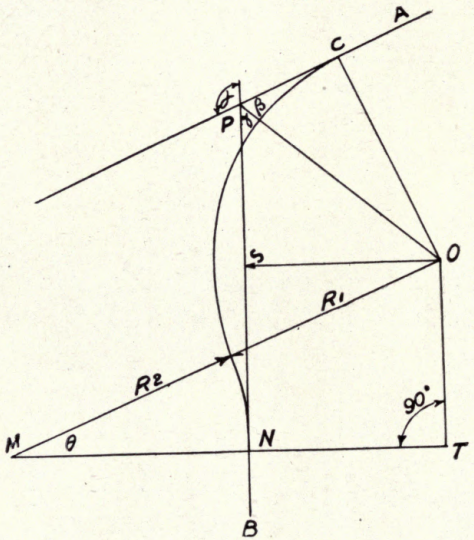



Fig. 16A.

$$OS = PO \sin \gamma.$$
$$MN = R_2.$$
$$MT = R_2 + OS = R_2 + PO \sin 8.$$
$$\text{Cos } \theta = \frac{MT}{R_1 + R_2} \qquad (1).$$
$$SN = (R_1 + R_2) \sin \theta.$$
$$PS = PO \cos \gamma.$$
$$\text{Tangent length PN} = (R_1 + R_2) \sin \theta + PO \cos \gamma \quad (2).$$
$$\text{Angle COM} = (180^\circ - \alpha + \theta) \qquad (3).$$

From the results of equations (1), (2), and (3) all the data required to set out the curves can be obtained.

# APPENDIX B

## THE "ROMAPAC" COMPOUND RAIL.

The problem of the renewable rail head has been very attractive and equally elusive to a considerable number of inventors; there have been many signal failures and as far as the writer knows only one system has achieved any measure of success under actual working conditions. The system referred to is styled "Romapac" and is the invention of Mr. Edgar Rhodes, M.I.Mech.E., a well-known Leeds engineer. Only two lengths of this rail have been laid in this country and these are on the Leeds Tramways and were

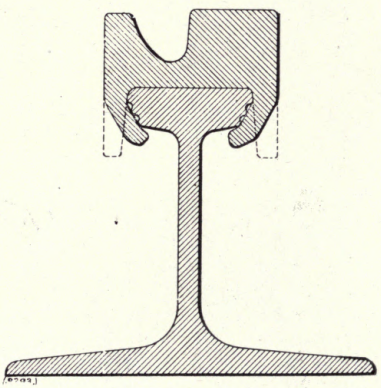


Fig. 1B.—Romapac Compound Rail.

laid under the supervision of the writer. A considerable length has been laid in the United States, where the inventor and his company are executing some large contracts at the present time, and a certain amount has been put down in Paris, both on the underground railways and on the tramways. The "Romapac" rails in use on the Leeds Tramways have seen over seven years service on a route which is subjected to an exceptionally heavy and frequent service of cars, at high speeds; in addition to which the track is utilized by vehicles of all descriptions carrying the heaviest products of the neighbouring engineering works. Whilst some parts of these lengths of rails, nearly a track mile, are not quite sound, the faults have been there since the commencement, and are

entirely due to the inexperience of the operators at that time. The writer considers that it is possible, with due care, to make a satisfactory job with these rails; but it will not be possible to effect such a saving in the cost of reconstruction as is claimed by the proprietors of this process. In nearly all cases it will be necessary to relay the whole of the paving, not merely a few setts on either side of the rails as suggested by the company in their particulars. It is obvious that a saving of about 50 per cent. or

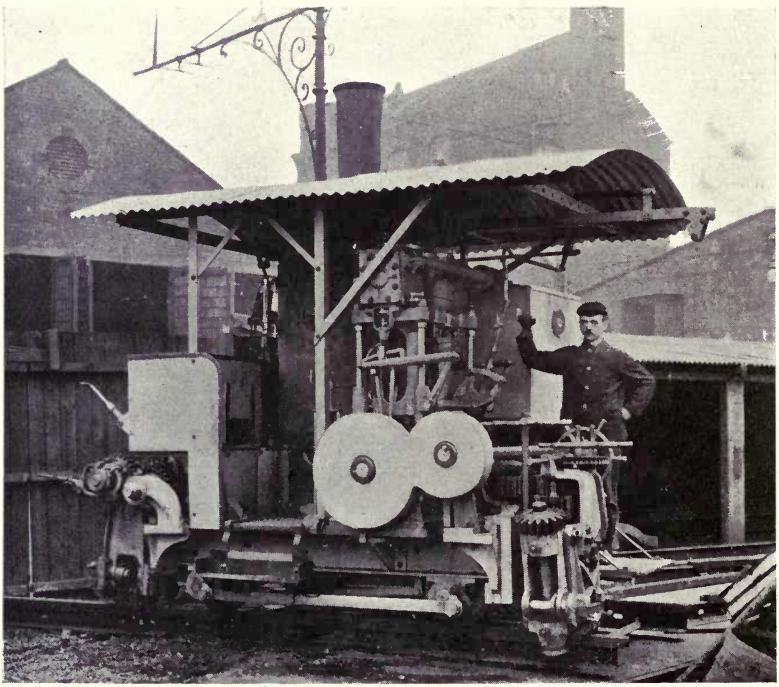


Fig 2B – The Romapac Machine.

more will be effected in the cost of rails, tie-bars, anchors, etc. The special apparatus employed comprises a portable steam driven machine for rolling on, bending and removing the head of the special rail shown in Fig. 1B.

The machine consists first of all of a locomotive with double cylinder inverted engine, $7\frac{1}{4}$ inches bore × 10 inches stroke and vertical multitubular boiler 3 feet 6 inches diameter × 6 feet high with ninety 2-inch tubes, having four coupled wheels 1 foot 3 inches diameter, with a wheel base of 5 feet 6 inches, adjustable

to suit any gauge, and fitted with two-speed gear 2 to 1 and 20 to 1. The ends of the frame are of planed cast iron and form cross slides. The Rolling and Cutting Machine is mounted on a saddle which fits on the front cross-slide. The Breaking-off or Stripping Machine is mounted on a saddle fitted to the back cross slide. These machines are driven by means of steel cross shafts, having a key-way cut their full length, upon which are sliding pinions with feathers, allowing the machines to follow curves. The machines are fitted with lifting gear so that they can be lifted clear of the road when travelling to position on the rail, and also so that they may drawn across the cross slide, and lowered on to each rail to be rolled on or removed.

The machine is run over the track with the loose head in position and lateral pressure is applied to the depending flanges of the head rail, by means of the rollers shown in Fig. 2B, until they are entirely enclosed about the head of the girder base rail, Fig. 1B. In order to remove the upper section from position, when worn, a circular cutter is fixed in place of one of the rollers used in the first process and a deep cut is made in the side of the rail head, partly severing one of the flanges, and the whole of the flange is then removed by means of a powerful, high speed stripping attachment A decided advantage possessed by these rails lies in the fact that a "bridge joint" is obtained by placing the joint of the lower section beneath the centre of the upper section.

The table appended shows the result of a test, made at the Sheffield Test Works, to determine the force required to slide the top section of the bottom section on a specimen 12 inches long:—

| Weight per Foot. | Length. | Pressure applied in Tons. Movement of Top Section over Bottom Section. | | |
|---|---|---|---|---|
| 33 lbs. | 12 ins. | 16·32 tons. | 18·21 tons. | 23·30 tons. |
| | | 0·02 ins. | 0·12 ins. | 0·26 ins. |

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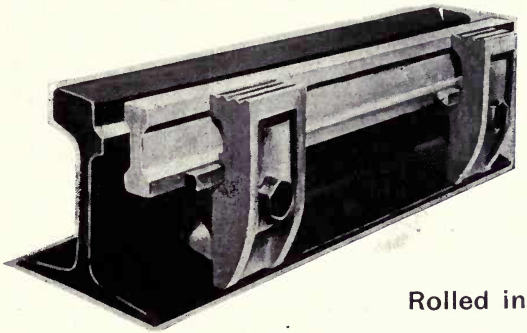

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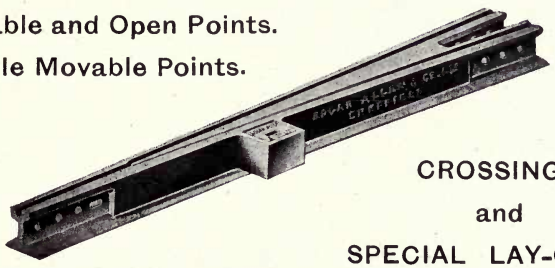
ALLEN'S IMPERIAL MANGANESE STEEL.

Movable and Open Points.
Double Movable Points.



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is applicable to all Road Construction.

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to secure elastic and quick-setting concrete.

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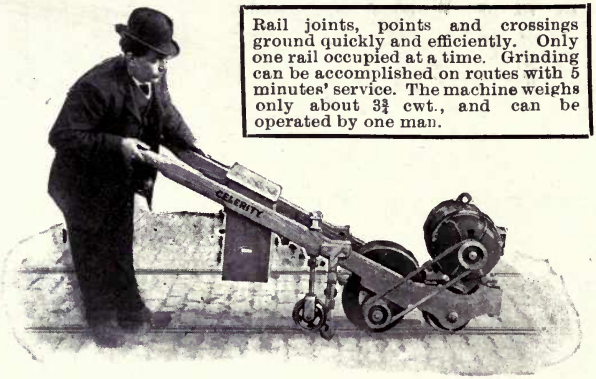


Rail joints, points and crossings ground quickly and efficiently. Only one rail occupied at a time. Grinding can be accomplished on routes with 5 minutes' service. The machine weighs only about 3¾ cwt., and can be operated by one man.

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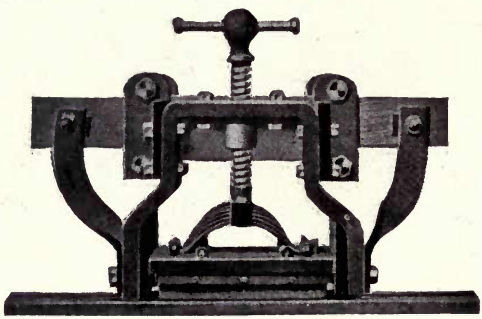

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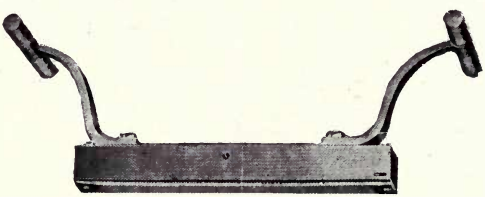

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Works area 100 acres.

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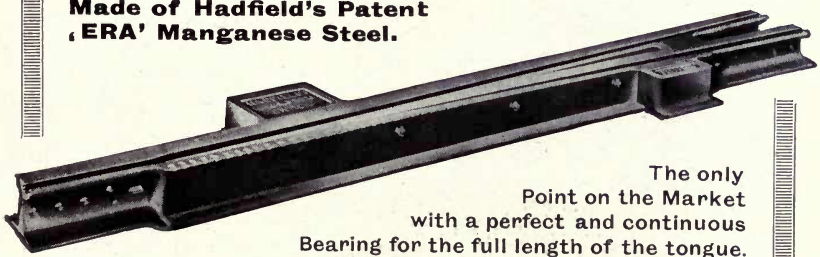
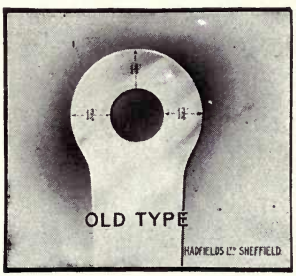
**Made of Hadfield's Patent 'ERA' Manganese Steel.**



The only Point on the Market with a perfect and continuous Bearing for the full length of the tongue.

**BEARING SURFACE AT HEEL END.**
Actual width of effective Bearing Area in this design only $1\frac{3}{4}$" around pin.

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The area of the Bearing Surface where the heel of the tongue rests has been increased to the utmost limit consistent with utility.
The tongue can be renewed, or adjusted for wear, in a few minutes without interfering with the paving.
The patent mechanism for moving the tongue is acknowledged to be unique for its simplicity and originality of design.

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THE SUPREME MATERIAL
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Roads laid with voidless asphalt macadam are dustless, durable, waterproof and sanitary. They are cheaper than any other first-class road, both in first cost and maintenance.

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## Imperial Simplex Portable Plant ::

As supplied to the

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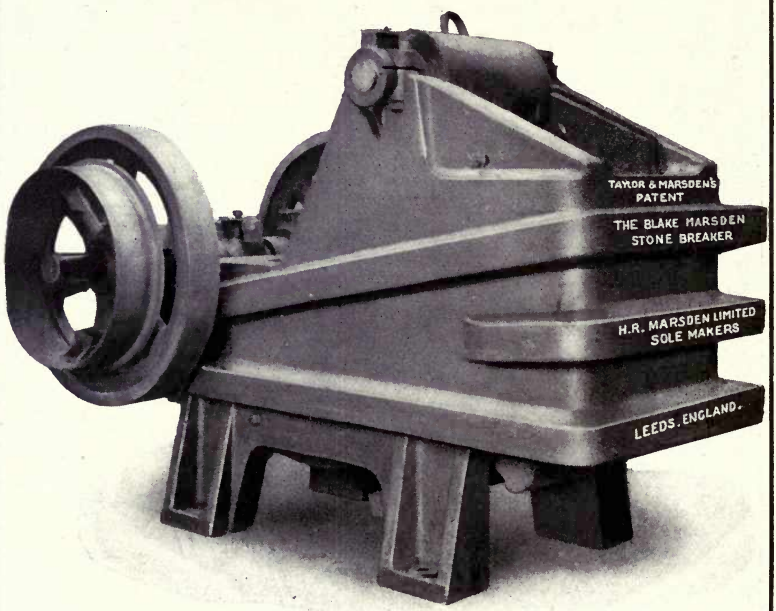


Photo of 24-in. Machine.
Improved Blake-Marsden Frictionless Lever, Hammer-Action Stone Breaker.
(Patented 1913.)

The stiffening along the lines of greatest stress makes this the stoutest and most reliable Stone Breaker built. All the best features of the usual

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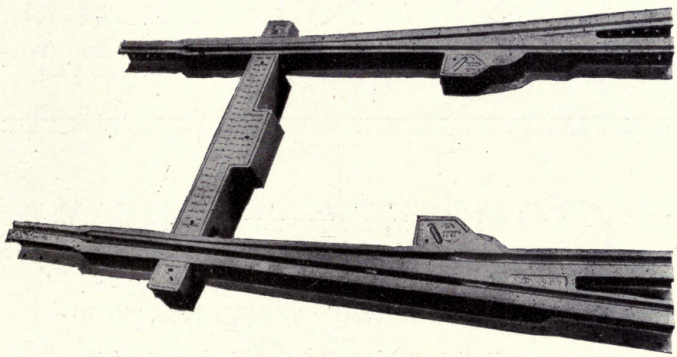

## TRAMWAY SPECIAL WORK.

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Manganese Tadpole Switches and Insert Type Mates and Frogs with Open Hearth Steel Rails.

SPECIAL CONSTRUCTION.

Manganese Tadpole Switches, Mates and Frogs with Manganese Steel Rails.

## OPEN HEARTH STEEL RAILS.

| | CLASS A. | CLASS B. |
|---|---|---|
| C. | ·60 to ·75 | ·70 to ·85 |
| Mn. | ·60 to ·90 | ·60 to ·90 |
| Si. | Not over ·20 | Not over ·20 |
| Ph. | „ „ ·04 | „ „ ·04 |

TENSILE STRENGTH IN LBS. PER SQUARE IN.

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Both Classes Withstand High Physical Tests.

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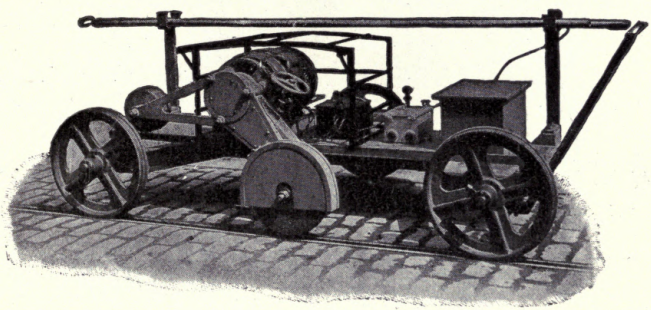

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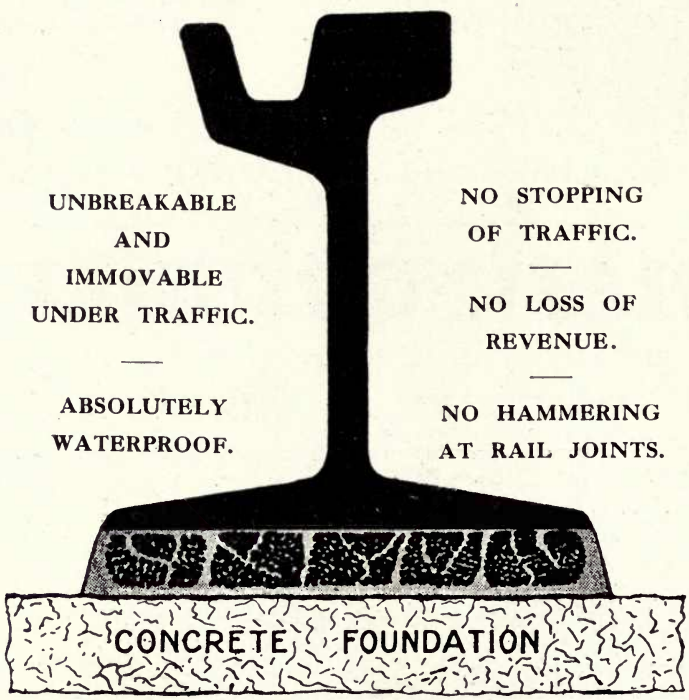


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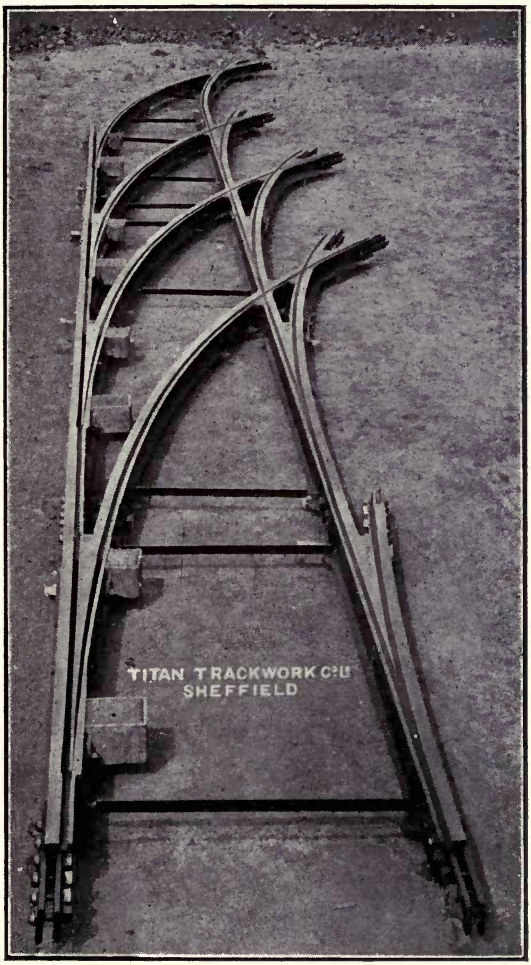
OSBORN'S **"TITAN"** MANGANESE STEEL.

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*Sole Proprietors:*

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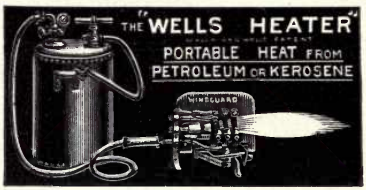


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An improved type of Lamp producing a Powerful Light from Carbide of Calcium.

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This Lamp is very simple in construction. No skilled labour is required. It can be charged and put to work in five minutes, and will then run until the carbide is exhausted.

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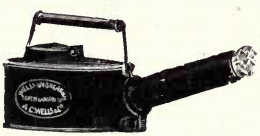


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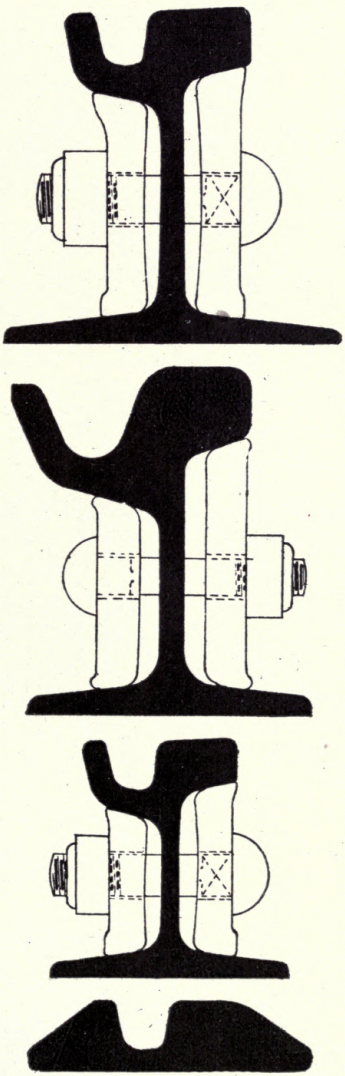

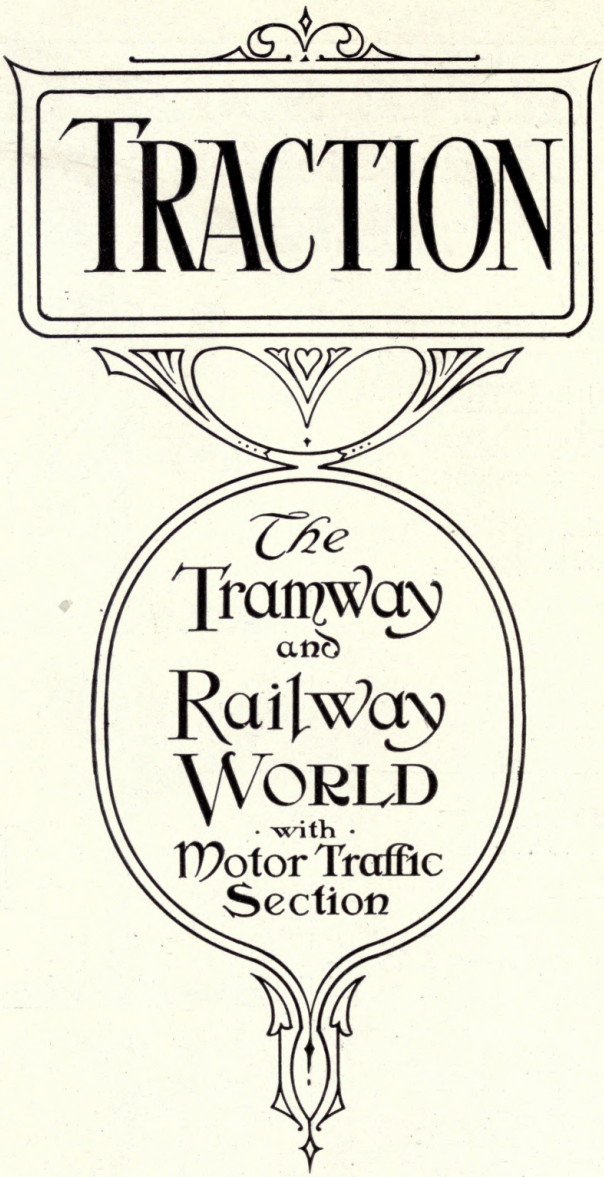


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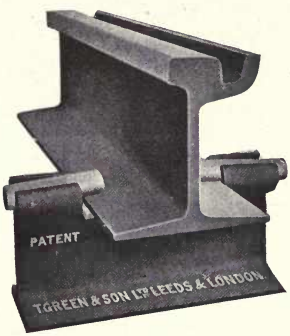


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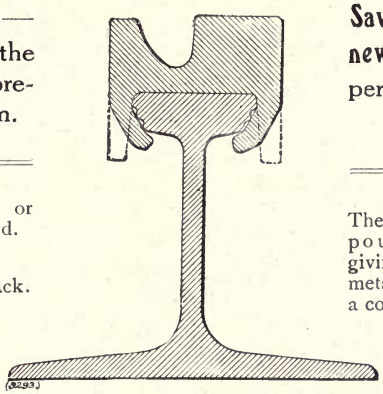

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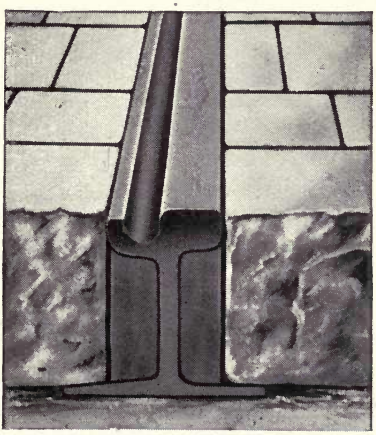

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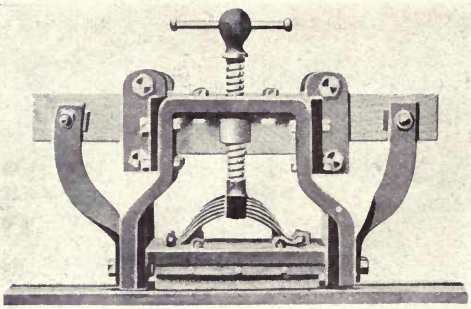

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Actual cost of removing Corrugations 1/32 in. deep, including labour, current and material,
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**VENTILATION**

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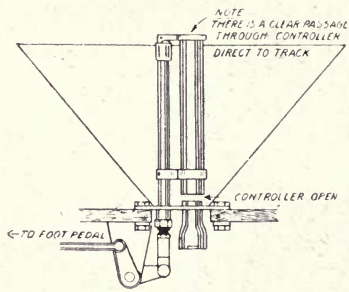


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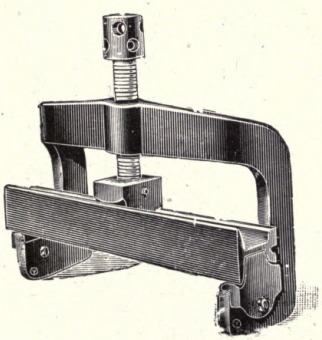

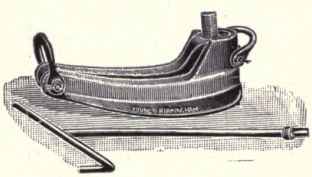

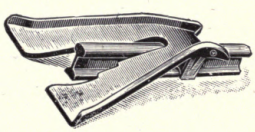

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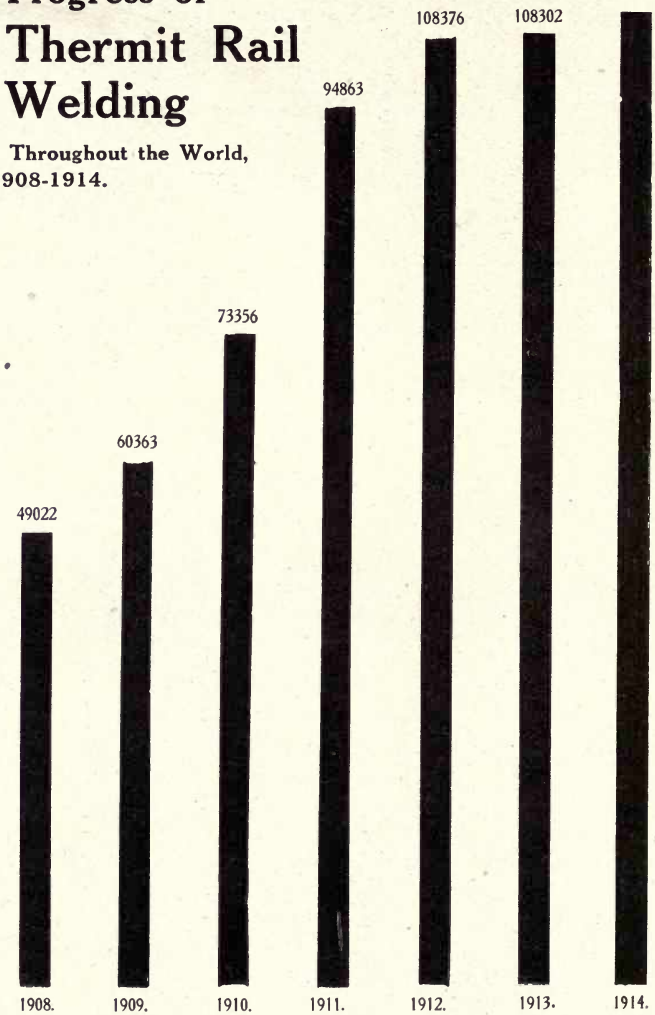


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